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1.—The Potential of Some Native West Australian Plants as Pasture Species

Presidential Address, 1958

By A. J. Millington, D.Sc. (Agric.)*

Delivered 21st July, 1958

It is in the tradition of this Society that first consideration should be given to the things which are ours. The rocks which underlie us, the soils which develop on those rocks, the plants which grow on those soils and the animals which eat those plants have been the subject of previous Presidential addresses to this Society. The most recent of the addresses on geology was that of the immediate past-President, Dr. Wilson. Professor Teakle in 1938 made the first detailed attempt to regionalise West Australian soils and in 1942 Mr. Gardner's address related the native vegetation to the soils and climate of the State. More recently Professor Grieve (1956) has discussed the physiology of the native plants, particularly in respect to drought resistance and Dr. White (1958) has reviewed them as sources of drugs of economic importance. It is their potential as forage plants that it is proposed to examine tonight.

On maps showing the Centres of Origin of Cultivated Plants, Australia is a conspicuous blank. This is partly due to biological chance, but also, and quite importantly, probably, to the fact that the Australian native never interested himself in agriculture. The great civilisations of the world followed the domestication of wild species. The Mayas in Mexico used maize, the Incas of South America depended on the potato, while the civilisations of Asia including our own and those of China and India were built upon the use of cereals, principally wheat and rice. By contrast, no very serious attempt was made to use any indigenous Australian plant for human food, although a number are probably not inferior in productivity and nutritive value to the wild ancestors of many species cultivated elsewhere. In the words of Charles Darwin "primitive man ate anything which he could chew and swallow" and the Australian native never rose above fern-like nardoo.

The agriculture and much of the pastoral industry of Australia is dependent, therefore, on the use of introduced plants, developed by older civilisations, with no serious attempt to domesticate, or even to preserve, the indigenous flora. Many species have become either totally or very nearly extinct, and, unfortunately, the palatable ones, with the greatest agricultural potential, are those most likely to be exterminated by rabbits and man's grazing animals.

The position of Australian plants in relation to extinction is not unique for it is likely that many of the common forage plants have survived only because recurrent wars and pestilence depopulated at fairly frequent intervals, the countries in which they originated. This gave the plants opportunities to adapt themselves to man and his grazing animals.

By contrast Australian plants have had no such opportunities. Sheep numbers were high sixty years ago while the modern plough and the tractor have subjected plants to more frequent and thorough cultivations than were possible in earlier civilisations. The lesson of evolutionary biology is that failure to compete and adapt to changing climatic and other conditions results in extinction, but practically nowhere in the world do we find plants which have the innate capacity for adaptation to the cataclysmic changes which come with modern land development. By the same token, never before have so many tools been available to achieve, in the words of the Russian scientist Vavilov, "evolution by the will of man".

Sheep numbers in Australia

1890	—	97	million
1940	—	125	,,
1946	—	95	,,
1957	—	150	,,

The rich and unique flora of Australia appears to be destined for extinction either by overgrazing or by competition from introduced plants, an eventuality which most Australians appear to contemplate with complete equanimity.

Occasionally our attention is directed to the fame which our Eucalypts have achieved overseas, or, as in South Africa, a tannin bark industry has been developed on the basis of an Australian plant, the wattle.

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Following its accidental introduction as an impurity in commercial Rhodes grass seed an Australian grass, *Dicanthium sericeum* syn. *Andropogon sericeus* has become dominant in parts of Texas and local ranchers are now gathering seed for extensive plantings. This particular grass has been "eaten out" over extensive areas in its native habitat in Queensland, but research work is now being undertaken at the Gatton Agricultural College with a view to selecting superior strains and three have been distributed for regional testing.

In the agricultural areas development was dependent on introduced cereals and with the increasing importance of pastures, it has been the most practicable procedure to seek grazing plants from the same source. While these plants have evolved in areas of similar climate, they have developed, for the most part, on soils, which, for geological reasons, are of much higher inherent fertility than those used for agriculture in this continent. In Western Australia, the lateritic soils, which cover three quarters of the agricultural areas already developed and characterise the ten or fifteen million acres remaining, are extremely poorly supplied with plant nutrients. Before introduced plants can be grown on these soils, massive and expensive applications of superphosphate and trace elements are required and there is evidence that on deep sands, potash fertiliser will be required. Within a very short space of time, decisions in respect to considerable areas will need to be taken as to whether they are to be worked at a high, or a low plane, of plant nutrients. Whether it will be more profitable to spend heavily on fertilisers and farm at a high level of productivity, or economise and carry many fewer sheep, can only be determined on the basis of experimental data, but there can be little doubt that the cost of fertilisers will be of paramount importance on the millions of acres of sandplain soil at present in use, or about to be used, in the more favoured rainfall areas of this State.

By contrast to the introduced legumes, the native plants grow and thrive with little or none of the expensive diet of nutrients applied as fertilisers. For a State, such as Western Australia, which has an annual fertiliser cost of at least £10,000,000 this is of importance. To approach the climatic potential of the State, an annual outlay on fertilisers of twenty to thirty million pounds will be required each year.

Any decision to develop species for economic purposes should be made on the basis of such data as are available from practical experience and scientific research.

The pastoral industry depends on native plants but overgrazing by sheep and rabbits, has greatly reduced the carrying capacity of these regions. This has lead to the belief, that native species will not withstand grazing, but investigations by the Department of Agriculture in the north of this State have clearly demonstrated that given relatively simple management, in the form of deferred grazing, the native plants of these areas can be made as productive as ever (Nunn and Suijdendorp 1954). Where over-grazing has proceeded to the point of extermination, such as around watering places, there is the opportunity to introduce superior strains of local species.

Assuming that it appears to be worthwhile to consider the problems likely to be encountered in domestication they can be summarised as (i) collection, classification, crossbreeding and selection, (ii) small scale trials to make a first assessment of the agronomic potential of the various strains and species, (iii) seed increase with its associated problem of seed gathering and (iv) controlled large scale trials under practical conditions with the most promising types. A reasonable approach could be made at a level of annual expenditure of £30,000-£50,000 per annum over a period of 10-20 years, or a total, at its highest level of annual expenditure and maximum duration of less than 10% of one year's fertiliser bill.

All agricultural countries are interested in legumes, not only as pioneer species on new and worn out land, but also for their high protein content. Of the native legumes, the *Swainsona* species are at present, probably the most important. An investigation of their economic potential was made by A. W. Humphries as part of a programme of research commenced at the University of Western Australia, Institute of Agriculture, under Professor E. J. Underwood's direction in 1950. This programme resulted from the belief that native legume species and particularly those from the wheatbelt and pastoral areas had, in view of their adaption to the climate, a potential as economic plants. Some of the 52 species of *Swainsona*, native to Australia, are toxic but *S. occidentalis*, known as "purple vetch", is an important fodder species in the Murchison region and *S. canescens* in the north-east Goldfields area of this State. (Fig. 1).

The second genus of legumes investigated in this programme, the *Kennedya* is confined, except for one species *Kennedya prorepens* to the agricultural and dairying areas of the State. All are perennials of high palatability to livestock and are prominent in a disturbed habitat such as that following clearing and burning. They usually do not persist under the subsequent grazing and a factor contributing to this is the 80% or so of hard seeds which do not germinate for some years, so that there is no immediate regeneration despite heavy seeding (Silsbury 1956).

Replicated sward trials were planted at Meckering in 1952 to compare the productivity of seven *Kennedya* ecotypes relative to lucerne, sub-clover, peas and vetches. All the perennials were cut back in May, 1953 and the plots sampled in November, 1953 and again in November, 1954

TABLE I

Meckering Yield Trial

Species	Yield cwts./acre (dry weight)		
	May, 1953	Nov. 1953	Nov. 1954
K. prostrata (Northam)	15·0	22·5	20·0
K. stirlingii	3·7	11·4	16·2
Lucerne	0·6	2·0	0·6
Dwalganup sub-clover	....	11·5	....

for yields which showed that some of the native plants tested were comparable and even superior to the introduced ones in productivity (Silsbury 1958). Yield data for the two most productive *Kennedya* types, relative to lucerne and sub-clover, are given in Table I.

Fig. 1.—*Swainsona oroboides* growing at Cook on the Nullabor Plains where the average annual rainfall is six inches.

Trials were conducted also, at Merredin Research Station to obtain data on the effect of various times of cutting on the Northam strain of *K. prostrata*. Comparative trials with introduced legumes on the lighter soil types at Merredin proved abortive because these failed to nodulate and regenerate.

TABLE II

Merredin Research Station 1953-54
K. prostrata planted May, 1952

Time of cutting	Yield cwt./acre (dry matter)
3rd June, 1953	6·8
3rd September, 1953	9·7
3rd November, 1953	(16·3 plus 1·6 seed) 17·9
3rd March, 1954	5·9

The lower yield of the March cut was due to the loss of foliage following seeding. This trial was on a relatively small scale and border effects became apparent due to the depletion of the subsoil moisture to the maximum depth of sampling, 42 inches. The seeding re-establishment was relatively poor but despite the dry seasons the *Kennedya* appears to have become stabilised and in 1958 there was a considerable germination of seedlings in mid-June.

As Silsbury has pointed out, *Kennedya* is one of the few perennial legumes which are adapted to survive in a Mediterranean climate and in view of his demonstration of its capacity to produce commercial yields, the development of suitable methods of management may well be justified. (See Fig. 2).

While some *Kennedya* species may have a place in the general agriculture of this State, native species have already demonstrated their value in reclaiming salt affected soils. It has been calculated that 5% of the agricultural areas of the State are affected by salt and although this is a small percentage of the total, it amounts to a million or so acres. The problem has various manifestations, but the continued utilisation of these soils is dependent on the use of salt-tolerant plant species.

Research by the Department of Agriculture showed that for seepage areas a grass, *Paspalum vaginatum* obtained by the Waite Institute from South Africa, was very satisfactory, but as it set no seed, it could be established only from cuttings. This method of establishment is not easily achieved over large areas and investigations were made at the University Institute of Agriculture by Carpenter (1958) with a view to developing a free seeding type. He found that *P. vaginatum* was native also to the Queensland coast and that this type did set a little seed under Perth conditions.

Fig. 2.—*Kennedya prostrata* (Crawley ecotype) has a depth of root penetration of over six feet compared with 15-18 inches for sub-clover (right in above photo). This enables it to bring moisture and nutrients from a considerable depth.

Material forwarded from Cheyne Beach near Albany by Col. Bleechmore was also self-sterile, but by crossing the different types, relatively good seed setting was obtained. It may well be that the grasses collected from Albany are native to the region.

Fig. 3.—*Kochia brevifolia* being used to reclaim salt affected land in the West Australian wheatbelt.

Investigations of a number of ecotypes of another native salt tolerant grass, *Sporobolus virginicus* have been made at the Institute of Agriculture by Frith (1957) and these have shown that they are variable according to source of collection, but free seeding. The problem of establishing grasses on salt affected seepage areas from seed is therefore now largely a matter of commercial seed production.

Fig. 4.—The inherent variability in wild species is of great importance in a breeding and selection programme. One plant of Old Man Saltbush (*A. nummilaria*) made exceptional growth relative to others of the same species in the collection at Merredin Research Station.

TABLE III

Paspalum vaginatum

Type	Fertile Flowers
	Per cent.
South African selfed	0
,, ,, x Cheyne Beach	32
,, ,, x Queensland	13
Queensland selfed	11
,, x Cheyne Beach	50
,, x South African	44
Cheyne Beach selfed	0
,, ,, x South African	32
,, ,, x Queensland	45

The salt and blue bushes, *Atriplex* and *Kochia* respectively, are important genera in the pastoral areas of Australia. Working with funds provided by a New South Wales foundation, the George Aitken Pastoral Research Trust, A. W. Humphries, while a Research Officer of the Institute of Agriculture, asembled a collection of these and related genera. This collection showed that within each species there is a range of variability which could well be the basis for the development of superior strains for use in re-seeding "eaten out" areas.

Fig. 5.—*Glycine tabacina*, a native perennial legume, growing on the roadside near Bruce Rock in Western Australia. This plant has the capacity, which may have agricultural value, to regenerate from roots cut well below the surface and exposed to sunlight.

More recently the Department of Agriculture and Mr. B. Parker of Kulin have demonstrated the value of *Kochia brevifolia* for the reclamation of salt land. Not only does this perennial colonise the eroded areas, but it provides a reserve of very nutritious green fodder for use in periods of summer drought, so that there is a marked improvement in both the quantity and the quality of feed available on otherwise unproductive land (Fig. 3).

Kochia brevifolia is widely distributed over southern Australia and is not confined to salt-affected soils. Experimental work dating from 1937 at Merredin Research Station on the local ecotype included a series of feeding stuffs

analyses from material harvested during the period from August, 1941, to March, 1942. These investigations by the Department of Agriculture showed that the crude proteins ranged from 22% in October to 32% in March with figures as high as 35% for new growth. The vitamin A content during the early summer has been shown (Underwood and Conochie 1943) to be 12 mg/100 gr. on a dry basis compared with less than 2mg/100 gr. for the mature annuals in the pasture. Blue bush is very low in fibre and therefore should balance the normal dry feed, but D. H. Curnow has directed attention to its oxalate content of 6% on a dry weight basis. From these data it appears that *K. brevifolia* may well have a place on every wheat farm as a source of high protein and vitamin rich supplementary fodder, during the long dry summers and the Department of Agriculture is undertaking a seed increase programme to make it more freely available to interested farmers (S. T. Smith, personal communication).

While the native flora is already making a contribution and has a considerable potential, the problems associated with its domestication are considerable.

It is for this reason that the Royal Society has advocated the establishment of a Botanic Garden. To many such a Garden should not be a graveyard where the last sad vestiges of a once great flora would be preserved from total extinction. Rather, it should serve as a centre from which a vigorous programme of research and development, as well as preservation, could be inspired and co-ordinated. The legislation governing the conservation and utilisation of our flora is for the most part dated 1895, at least in concept, if not in enactment and a review of the position in the light of modern developments is long overdue.

It is visualised that a function of the Garden would be to provide funds, to enable the various organisations to conduct specific research projects, as part of continuing programmes of domestication and conservation.

The collection and maintenance of as many species as possible is an extremely urgent one, for delay will reduce the chances of ultimate success in plant domestication by restricting the range of material available. Already the list of native plants which are believed to be extinct is formidable and the heath flora is still disappearing at the rate of hundreds of thousands of acres per year. There is evidence that any uncultivated areas on farms will not persist, for sheep need roughage to balance a predominantly sub-clover diet. When Silsbury began his collection of species of *Kennedya* he was unable to locate one species and he had great difficulty in finding others which were, from botanical accounts, common and widespread during the earlier days of settlement. Within a few years great sections of our flora outside the forest reserves will be extinct and among them will be many with the greatest potential for economic development.

The need for a range of plants of any species is shown in the development of a disease resistant strain of the red-flowering gum, *Eucalyptus ficifolia* (Cass-Smith, personal communication). Only one tree in about four hundred carries the heredity for immunity to the fungal wound parasite which causes the die-back in trees of this species. It would be easy, therefore, to test one thousand trees without obtaining the desired immune one.

In addition to the urgent and immediate need for plant collection and preservation, research will be required into the problems of management, germination and nutrition. At the University Institute of Agriculture programmes of investigation on seed germination have been undertaken with some *Kennedya* species, *Atriplex* and *Kochia* genera. Most species have evolved controls which, while they make them well adapted to survive under natural conditions, create difficulties in respect to their use in agriculture, for the conditions under which seed will germinate obviously affects establishment.

With *Kennedya* Silsbury demonstrated that by scarification alone, germination could be increased from 15% to 62% which would be satisfactory for establishment. Firing gave no improvement in germination. Salt tolerant species are apt to germinate slowly and poorly. With the salt tolerant grass, *Sporobolus virginicus*, Frith found at the Institute of Agriculture, that germination was aided by both light and the fertiliser, potassium nitrate. He suggested that by planting the seed in narrow furrows with potassium nitrate, good germination and establishment should be obtained.

Establishment difficulties due to poor germination are usual with salt and blue bushes. Investigations by D. G. Wilcox at the University Institute of Agriculture have shown that seed disinfection with a fungicide such as organic mercury and planting in late autumn can markedly improve germination.

These studies apart from their direct value, have served to show that many of the serious barriers to the domestication of our native plants can be overcome by research.

The reliance on introduced winter growing annuals has resulted in the development of systems of grazing management to which the native perennials are not well adapted, for the scarcity of green feed during the summer can result in their being exposed to extremely high stocking rates. Every green supplement, high in protein and vitamin A is particularly valuable. When it is appreciated that on most wheat farms, about one half of the wool is grown during the four or so months of green feed, the value of such a supplement may be to achieve more than just the maintenance of the sheep in good health. Yields obtained by Silsbury with *Kennedya*, and Mr. B. Parker with blue-bush suggest that the quantity of fodder produced would be considerable.

It is likely that for native legumes controlled grazing will be necessary during the summer months but with *K. brevifolia*, protection from stock appears to be necessary only in the year of establishment. Consequently a few acres of *Kochia* in each paddock would provide a valuable summer supplement at very small cost.

Although the general experience is that native species do not persist under grazing, this may be a result of insufficient ecotypes being tested. It has been observed by Silsbury that *Kennedya prostrata* if heavily grazed will shoot from below the crown, while a glycine from near Shackleton

has been observed to regenerate from a root cut eight inches below the surface (Fig. 5). With *Swainsona beasleyana* at Mukinbudin, rabbits regularly cut the plants back to an inch or more below ground level without killing them.

At Kukerin Mr. A. R. Abbott has *Kennedya prostrata* which has persisted in a paddock that has been cropped and grazed for 40 years, while *K. prorepens* has survived 30 or so years of farming at Ghooli east of Southern Cross.

Before large scale grazing trials can be conducted, it will be necessary to obtain seed in commercial quantities. Dehiscence at maturity is a characteristic of wild species, but non-shattering types would greatly simplify seed collection. Such forms have been developed for most cultivated species and mutation induction by irradiation could be used if no suitable plants were found in nature. Plant breeders now have a wide range of chemical and other techniques for inducing variation, so that, given time, almost any plant could be tailored for domestication.

In considering the implementation of a new policy towards our native plants, the Royal Society is mindful that the National Parks Board of Western Australia is the organisation nominated by Parliament in the Act of 1895 to manage parks and reserves vested in the Crown. This Act instructs the Board to "Otherwise improve or ornament such parks or reserves and do all such things as are calculated to adapt such parks and reserves to the purposes of public recreation, health and enjoyment". While the demand for recreational areas is becoming greater each year, the need for an organisation with adequate funds and staff to ensure the preservation of our flora as well as its exploitation, is urgent and preferably its headquarters should be located, with the Herbarium, in a Botanic Garden.

It is only by having in existence such an organisation that adequate parks, both regional ones in the country and others in the city, could be created and maintained to serve the recreational as well as the economic needs of the community. The need to co-ordinate and classify research in such diverse fields as pharmacology and the physiology of salt tolerant grasses is self-evident, while there is little of tourist interest in this State once the wild flowers have disappeared. The Royal Society has prompted the Government to enquire into the possibilities of establishing such a Garden and related organisation and I feel sure that, as in the past, our leaders in public life today are statesmen who will give the proposals the careful and urgent consideration which they merit.

References

Carpenter, J. A. (1958).—Production and use of seed in sea-shore paspalum. *J. Aust. Inst. Agric. Sci.* 24: 252-256.

Frith, J. L. (1951).—The germination of *Sporobolus virginicus*. *J. Aust. Inst. Agric. Sci.* 23: 69-75.

Grieve, B. J. (1956).—Studies in the water relations of plants. I. Transpiration of Western Australian (Swan Plain) sclerophylls. *J. Roy. Soc. W. Aust.* 40: 15-30.

Nunn, W. W., and Suijdendorp, H. (1954).—Station management—the value of "deferred grazing". *J. Dep. Agric. W. Aust.* 3: 585-587.

Silsbury, J. H. (1956).—Studies in the genus *Kennedya* Vent. M.Sc. (Agric.) Thesis, Univ. W. Aust.

———— (1958).—Agricultural potentialities of the genus *Kennedya* Vent. in Western Australia. *J. Aust. Inst. Agric. Sci.* 24: 237-242.

Underwood, E. J., and Conochie, J. (1943).—Vitamin *A* in the nutrition of sheep in Western Australia. 2. The carotene content of pasture species. *Aust. Vet. J.* 19: 37-42.

White, D. E. (1958).—Recent advances in the chemistry of Western Australian plants. Presidential address, 1956. *J. Roy. Soc. W. Aust.* 41: 1-11.

2.—Permian Stratigraphy of the Woolaga Creek Area, Mingenew District, Western Australia

By G. Playford*

Manuscript accepted—August 1st, 1958

The Permian stratigraphy of the Woolaga Creek area, in the northern part of the Perth Basin, has been investigated in detail. The succession is similar to that in the classical Irwin River area, 18 miles farther north. There are, however, some significant facies variations between the two areas; in particular, the Irwin River Coal Measures are notably less carbonaceous at Woolaga Creek than in the type area. The sequence in the Woolaga Creek area, from the base upwards, is: Nangetty Formation, Holmwood Shale, High Cliff Sandstone, Irwin River Coal Measures, Carynginia Formation, Wagina Sandstone. A new unit, the Woolaga Limestone Member of the Holmwood Shale, is proposed formally herein. The member contains an abundant marine fauna including two goniatites, which indicate a Sakmarian age.

Notable features of the Woolaga Creek section include: the abundance of thin, lenticular beds of limestone in the Holmwood Shale; the presence of a marine fauna in the basal part of the High Cliff Sandstone; well-developed slumping in the Irwin River Coal Measures; conspicuous sandy intercalations within the Carynginia Formation; a single plant fossil locality in the Wagina Sandstone; and the sporadic recurrence of erratic boulders in all the formations overlying the Nangetty Formation, with the exception of the Wagina Sandstone. The Fossil Cliff Formation and the Beckett Member, well-known in the Irwin River section, are not represented at Woolaga Creek. The Irwin River Coal Measures and the Wagina Sandstone are considerably thicker than in the type area. The strata are believed to be of Sakmarian and Artinskian age. They record a sequence of marine and non-marine environments, including two distinct periods of barred basin deposition.

The sediments are on the down-thrown, western side of the Darling Fault, the major structural feature of the area. A gentle easterly tilt characterizes the strata, except in the vicinity of the Darling Fault, where they are deformed synclinally against the Archaean metamorphic complex. The Darling Fault appears to have a vertical or near-vertical dip. Small, usually antithetic, gravity faults are common within the Permian strata.

The lateritic surface of the flat-topped hills and tablelands in the area is representative of the once continuous, but now extensively dissected Victoria Plateau.

Contents

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Introduction

The Woolaga Creek area, as mapped in detail by the author, comprises approximately 20 square miles and is situated 200 miles north of Perth and 12 miles east of Mingenew (see Fig. 1). The area lies in the Victoria Subdivision of the South-West Land Division of Western Australia. It is situated within the following limits of latitude and longitude:—lat. 29° 09′ S. and 29° 15′ S., long. 115° 36′ E. and 115° 43′ E.

The Permian sediments of the Mingenew district have been the object of geological investigation and interest since the middle of the last century. Most of this work, however, was confined to the classical exposures in the Irwin River area, largely because of the economic possibilities of the Irwin River Coal Measures. The southern or Woolaga Creek area has been comparatively neglected and previously published work on this area is only on a broad reconnaissance scale.

The present investigation was undertaken to examine in detail the Permian stratigraphy of the Woolaga Creek area and to correlate the strata, as far as possible, with the well-known sequence in the Irwin River area, 18 miles to the north. The environment of deposition of the sediments has been studied as an integral part of the investigation.

In all, ten weeks were spent in the field, during which time the detailed mapping of the area was carried out and all outcrops were visited and examined. Palaeontological and lithological material was collected for subsequent laboratory examination. The detailed petrography is included in the author's thesis from which this paper was compiled; this thesis is in the library of the Department of Geology, University of Western Australia.

Vertical air photographs, supplied by the Department of Lands and Surveys, Perth, were used in the field mapping, together with the

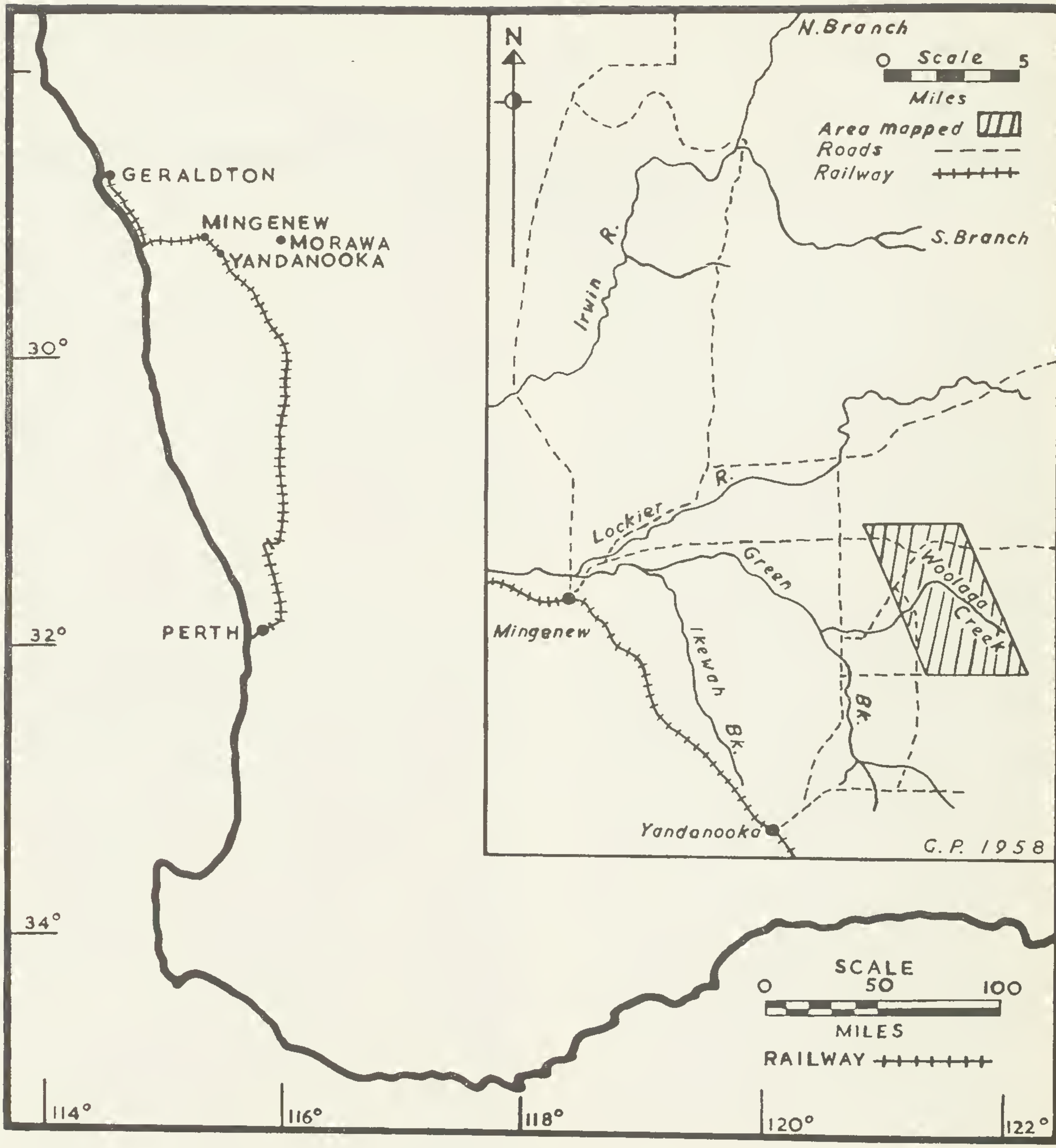

Fig. 1.—Locality Map.

Pintharuka one-mile-to-the-inch Army sheet. Information was obtained also from the maps of Campbell (1910) and Johnson, de la Hunty and Gleeson (1954).

The Army map was photographically enlarged approximately to air photograph scale and transferred to "Kodatrace" for use in the field. This was not satisfactory for a final geological map because many of the topographic features on the Army map had not been accurately positioned. Therefore, it was found necessary to redraft the base for the geological map of the area from the air photographs, laid out under satisfactory control. The Army grid was imposed on the geological map (Map 1) and all localities cited in the text are referred to this grid. Under this system the first three figures of the grid reference represent eastings, and the last three figures represent northings. For example, Red Hill has an east-west reading of 64.7 and a north-south reading of 83.8. Its grid reference is then given as (647838). A geological interpretation map (Map 2) and cross section (Fig. 3) were compiled on the basis of the geological map.

A tacheometer and staff were used in the detailed measurement of the Woolaga Creek stratigraphic section.

Previous Investigations

Reviews of previous geological investigations in the Mingenew district have been given in recent publications, notably in Clarke, Prendergast, Teichert and Fairbridge (1951), in Johnson *et al.* (1954), and in McWhae, Playford, Lindner, Glenister and Balme (1958). The following discussion on previous work will be confined to those papers having obvious application, or containing specific reference, to the area under consideration.

The work of Campbell (1910) was an outstanding contribution to the knowledge of the geology of Western Australia. As an Assistant Geologist with the Geological Survey of Western Australia, Campbell mapped a total area of 4,500 square miles, paying particular attention to the distribution and stratigraphy of the "Carboniferous and Permo-Carboniferous" rocks; many of his conclusions are still accepted and with considerable respect. For example, he was the first to recognize the glacial sequence in the area. The geological map compiled by Campbell embraces the Woolaga Creek area, although most of his references in the text are to the Irwin River section, because of its possible economic potential. However, he notes the presence of "carbonaceous seams" on Woolaga Creek, and his map shows two outcrops of erratic boulders to the east of the area mapped by the present author.

Woolnough and Somerville (1924) were concerned mainly with the valley of the Irwin River, and referred only briefly to the Woolaga Creek area. They suggested a probable correlation between the Woolaga Creek "bituminous seams" mapped by Campbell (1910) and the well-known coal seams on the North Irwin River. The "Main Glacial Horizon" was traced by these authors more or less continuously from the Irwin Valley to a point about 3 miles southwest of Mt. Budd.

A comprehensive review of the Permian stratigraphy of the Irwin River area is contained in the 1951 paper of Clarke and his co-authors. The structural hypothesis presented in this paper was based largely on air photograph studies by Fairbridge. Large-scale step faulting was considered the major structural pattern, as opposed to the old anticlinal hypothesis. Although containing only a brief reference to the Woolaga Creek locality, the importance of this publication to the present author is that it represents the first concise account of the Irwin River succession, with which a correlation of the southern section will necessarily be attempted.

In May, 1950, a party of senior students from the University of Western Australia carried out some plane table geological mapping at Woolaga Creek, under the direction of Dr. R. W. Fairbridge. This was not a detailed survey, and the most significant observations are to be found in Fairbridge (1952).

Two species of Permian ammonoids, *Metalegoceras campbelli* and *Uraloceras irwinense*, from the Holmwood Shale of the Mingenew district were described by Teichert and Glenister (1952), who recognized their Sakmarian affinities. The type locality was in the Irwin River area, but the authors stated that the two species were also found in a limestone band "in the southern part of the Irwin Basin south of the Lockier River," i.e. in the Woolaga Creek area. Their geological map shows the outcrop of the band in this locality.

In 1949, W. Johnson, L. E. de la Hunty and J. S. Gleeson, of the Geological Survey of Western Australia, mapped an area of 1,950 square miles, mainly by reconnaissance methods, in the Yandanooka, Mingenew and Eradu districts; the Woolaga Creek area was included in the survey. Their work was published in 1954. The object of this investigation was to determine the economic value of the Permian coal seams. Sufficient evidence was put forward in the publication to negate the commercial possibilities of this coal. Johnson *et al.* (1954) modified the rock unit nomenclature of the Permian succession proposed by Clarke and his co-authors and favoured a broad anticline as the overall structural feature, with accompanying modification by faulting. Theirs was the first attempt to trace the established formations of the Irwin River section into the little-known southern section at Woolaga Creek. A notable discovery was the marine fauna in the basal part of the High Cliff Sandstone at Woolaga Creek. Of necessity, their survey was on a regional scale, but they recognized the desirability of a more detailed study of the Woolaga Creek area in light of the excellent exposures in the locality and the probability of so gaining a more complete picture of the Permian succession in the Irwin River district. As outlined above, that is precisely the aim of the present investigation.

The most recent work in the Mingenew district, prior to that undertaken by the present author, was carried out by geologists of West Australian Petroleum Pty. Ltd., as part of a comprehensive, semi-detailed survey of the Perth Basin. Their work on the Permian sediments is summarized by P. E. Playford and S. P. Willmott in McWhae *et al.* (1958). The nomenclature of Playford and Willmott modifies slightly that of Clarke *et al.* (1951) and is followed in this paper.

Physiography

The Woolaga Creek area consists of sharply defined flat-topped uplands rising abruptly from broad sweeping lowlands, drained by narrow intermittent watercourses.

The flat-topped landforms of the area are characteristic of the northern part of the Perth Basin, and represent remnants of a once continuous plateau, the Victoria Plateau of Johnson *et al.* (1954). These uplands owe their preservation to the existence of a protective capping of duricrust, developed on the softer Permian strata and associated with the old Victoria Plateau; the transition of the larger expanses of the plateau to mesas and ultimately to buttes represents successive stages in circumdenudation. The highest hills in the area studied are Mt. Budd (598858) and Beere Hill (634856), at respective heights above sea level of 930 feet and 934 feet. Mt. Budd (Plate 1, 1) is a butte, whereas Beere Hill is a mesa. The

perfect example of a butte in its ultimate form is Red Hill (647838), a symmetrical cone-shaped hill (see Plate 1, 3).

The soft sediments of the Holmwood Shale underlie the western part of the Woolaga Creek area. Being highly susceptible to erosion these sediments give rise to a gently undulating lowland topography. Farther east, however, the greater durability of succeeding rock units results in a somewhat more rugged terrain, including relatively numerous and extensive flat-topped remnants of the Victoria Plateau. The cuesta in the vicinity of (632826) is a graphic illustration of the abrupt stratigraphic change from soft to generally more resistant rock types. This prominent feature, upon which is the site of the old "Glendevon" homestead, is composed of High Cliff Sandstone, which succeeds directly the soft Holmwood Shale.

Most of the area studied is drained by Woolaga Creek, a tributary of Green Brook, which in turn flows into the Lockier River. Ebano Creek passes through the north-eastern part of the area and is a tributary of the upper Lockier River. Several lesser streams emanate from the long line of breakaways in the south-western part of the area and find their way eventually into Green Brook. All of the streams in the area are dry for most of the year, flowing for a short time only after heavy falls of rain. Woolaga and Ebano Creeks and their tributaries provide fine exposures of the Permian strata in which they are incised.

The lower part of Woolaga Creek flows toward the south-west, perpendicular to the strike of the underlying sediments. Higher in its course, however, there is an abrupt change in direction so that upper Woolaga Creek has a subsequent character, flowing parallel to the strike direction.

In its upper reaches, Woolaga Creek receives several tributaries flowing from the east and traversing the Darling Fault high in their courses. One of these, entering the main creek at (655821), is of particular interest. In the upper part of its course this stream has cut a fairly deep, V-shaped gorge in the Precambrian terrain and has a moderate grade. To the west, on crossing the Darling Fault, the stream exhibits an immediate and striking change in character. It begins to meander freely and attains a notably lower gradient. This pronounced change in stream character, which is well-shown by the air photographs, can be related directly to a similar change in the nature of the underlying rocks—from the highly resistant Precambrian metamorphic complex on the east to the soft abutting sediments of the Permian Caryngina Formation on the west side of the Darling Fault.

In contrast to Woolaga Creek, the lower and upper parts of Ebano Creek are respectively parallel and transverse to the strike of the Permian strata. The change in direction of Ebano Creek occurs stratigraphically just below the boundary between the Wagina Sandstone and the softer, underlying Caryngina Formation. The suddenly acquired subsequent character of the creek appears to be, therefore, the direct result of the equally sudden change in the durability of the strata. Ebano Creek does not change significantly in character on passing westwards over the Darling Fault. This is because the resistance to erosion of the massive Wagina Sandstone, which is truncated by the Darling Fault in this vicinity, does not differ markedly from that of the adjacent Archaean rocks.

Johnson *et al.* (1954, p. 33) considered it probable that river capture had occurred between Woolaga and Ebano Creeks. However, there is no geomorphological evidence in the area to support this suggestion. The relatively high-level, undissected strip of country separating upper Woolaga Creek from lower Ebano Creek could scarcely be considered the site of a former gorge or water gap; this would necessarily be the situation if the two watercourses were once connected.

Water supply is a problem for many farming properties in the Woolaga Creek area, and there is a continual search for supplies of potable or even semi-potable ground water. The position is generally worse in the western lowlands, underlain mainly by the impervious, saline Holmwood Shale. Four unsuccessful bores were drilled recently in the western part of the area. Three of the bores, at (635824), (638821) and (654805), penetrated High Cliff Sandstone before passing into Holmwood Shale in which they were abandoned. The other bore, sited at (629823), penetrated Holmwood Shale for its entire depth. However, there are some wells in the western lowlands that yield good supplies of useful water. None of these penetrates the Holmwood Shale and they are generally located on the higher slopes of the lowlands. For example, at (620845) and at (636827), good supplies of excellent stock water are obtained from sandstones stratigraphically higher than the Holmwood Shale. Also, at "Milford" homestead in the south-western part of the area, abundant water for stock and domestic purposes is obtained from a well penetrating fine yellow sandstone of the Nangetty Formation, which is stratigraphically below the Holmwood Shale. Ebano Spring (640861) provides the best supply of ground water, both quantitatively and qualitatively, in the whole of the area. The water in this instance is derived from the Wagina Sandstone, the uppermost unit of the Permian succession.

General Geology

Introduction

In Western Australia the Permian System is developed in the Perth Basin, the Collie, Muja and Wilga Basins, the Carnarvon Basin, the Canning Basin and probably also in the Bonaparte Gulf Basin. Permian sediments are known from the Perth Basin only in its northern part, where the thickest and most continuous sequence occurs in the Mingenew district.

The Darling Fault is the outstanding structural feature of West Australian geology. McWhae *et al.* (1958) state that it extends meridionally for approximately 600 miles from the south coast to near the south end of the Carrandibby Range. On geophysical evidence, Thyer and Everingham (1956) considered that the Darling Fault has "a maximum throw of perhaps 30,000

feet or more." It represents the well-defined eastern boundary of the Perth Basin, marking generally the junction between the sediments and the Archaean rocks. Thus, from the vicinity of Arrino, through the Mingenew district to as far north as Mullewa, the Permian sediments are bounded on their eastern margin by the Darling Fault. The West Australian Precambrian Shield extends eastward from the fault line to form the Darling Plateau.

In the Woolaga Creek and Irwin River areas, the relationship of the Permian to the underlying rocks is not visible. However, to the south, in the Yandanooka area, the basal part of the Permian succession overlies unconformably the Yandanooka Group of Proterozoic or early Palaeozoic age. Where Permian rocks overlie the Archaean complex directly, Johnson *et al.* (1954, p. 42) have noted that the actual contact is always obscured by alluvium.

Archaean

The stable crystalline complex, which abuts the Permian sediments along the Darling Fault, is composed of high-grade metamorphic rocks of Archaean age.

The north-north-westerly trending Yandanooka Hills, several miles south-west of the area studied, are composed of Archaean metamorphics. This prominent structural feature was termed the Mullingarra Axis by Woolnough and Somerville (1924). Archaean rocks also crop out in the Brockman Hills, some 5 miles west of Mt. Budd, immediately north of the Mingenew-Morawa road; as stated by Woolnough and Somerville, this small Archaean inlier represents a northerly continuation of the Mullingarra Axis.

Between the Darling Fault and the Archaean Mullingarra Axis, later sediments obscure the down-thrown basement. Thus, in the Woolaga Creek area, Archaean rocks are presumed to underlie the Permian strata at considerable depth.

Beyond the Darling Fault, adjacent to the area studied, the outcrop on the Archaean terrain is generally poor, and there is widespread development of laterite. The major rock types observed were granitic gneisses and hornblende gneisses cut by quartz-feldspar pegmatites and dolerite dykes. The foliation of the gneisses dips steeply, generally to the west, with an average strike of 140°. This conforms closely to the usual north-west tectonic trend of the Central Province of Prider (1952), who considered that the Archaean rocks of this province had been isoclinally folded on north-westerly trending lines. Reliable lineation data could not be obtained; the few readings taken indicated a wide variability.

The fault contact between the Permian strata and the Archaean metamorphics is rarely exposed in the area, although the air photographs display the Darling Fault strikingly as a pronounced north-north-westerly trending line. It is an example of a major geological structure, the nature and extent of which is clearly evident when viewed from the air, but which is not immediately perceptible when inspected at close quarters. From an examination of the air photographs supplemented by field observations, it is apparent that a number of factors have been effective, both individually and collectively, in accentuating the line of the Darling Fault on this large scale. The following is a brief account of these factors:—

(i) Two tributaries of upper Ebano Creek have excavated the fault line in the north-eastern part of the area.

(ii) A marked change in the character of streams traversing the Darling Fault is apparent in one locality; this has been described under **Physiography.**

(iii) Several tracks formed by both human and animal agencies follow parts of the Darling Fault line. The most striking of these is a vehicular track which extends south from the Mingenew-Morawa road, half a mile east of Ebano Spring, closely following the fault line for two miles.

(iv) A prominent escarpment marks the Darling Fault in the vicinity of (664833). This feature, which may be classed as a resequent fault line scarp (Cotton 1945, p. 178), has resulted from the preferential erosion of the soft Carynginia Formation adjacent to the Archaean metamorphics.

The Wagina Sandstone, stratigraphically above the Carynginia Formation, offers more resistance to erosion. Consequently, farther north, where this sandstone formation abuts the Archaean complex, no such escarpment has developed, although here other factors serve to emphasize the fault line.

(v) In some places, the Darling Fault line is marked on the air photographs by a thin, white line, other than a track. When examined on the ground this is generally found to be a narrow zone of steeply dipping Permian strata, immediately adjacent to the fault. At one locality (679799), the fault line is marked by a low ridge of travertine, which is about 15 yards wide.

(vi) Plant distribution accentuates the trace of the Darling Fault in many places. The line of the fault itself generally supports a prolific growth of shrubs and trees, which is particularly noticeable in areas of sparse vegetation. In such areas, the Darling Fault is displayed on the air photographs as a dark, narrow line of timber, surrounded on either side by areas of scattered vegetation. Also, the composition and density of the flora often differ notably on either side of the fault line.

(vii) Abrupt changes in soil type on passing from one side of the Darling Fault to the other, are usually shown by the air photographs as subtle, but equally abrupt variations in "tone". This is, of course, restricted to localities of subdued topography where the soils are mainly residual over the Permian and adjacent Archaean rocks.

For edaphic reasons, factors (vi) and (vii) are closely inter-related, the one augmenting the other.

Permian

The Woolaga Creek and Irwin River areas provide the two best sections of Permian strata in the Perth Basin. Elsewhere in the basin, Permian rocks are known from bores and poor surface exposures in the Yuna-Eradu district, where they are largely covered by horizontal Jurassic sediments. The basal unit of the

Permian succession, the Nangetty Formation, is found overlying the Proterozoic or early Palaeozoic Yandanooka Group as far south as Three Springs.

The present author has been able to confirm the presence in the Woolaga Creek area of a stratigraphic sequence which is essentially similar to that developed in the well-known Irwin River section (see Fig. 2). A notable difference between the two sections is the absence of the Fossil Cliff Formation in the Woolaga Creek area; this formation is a well-known unit

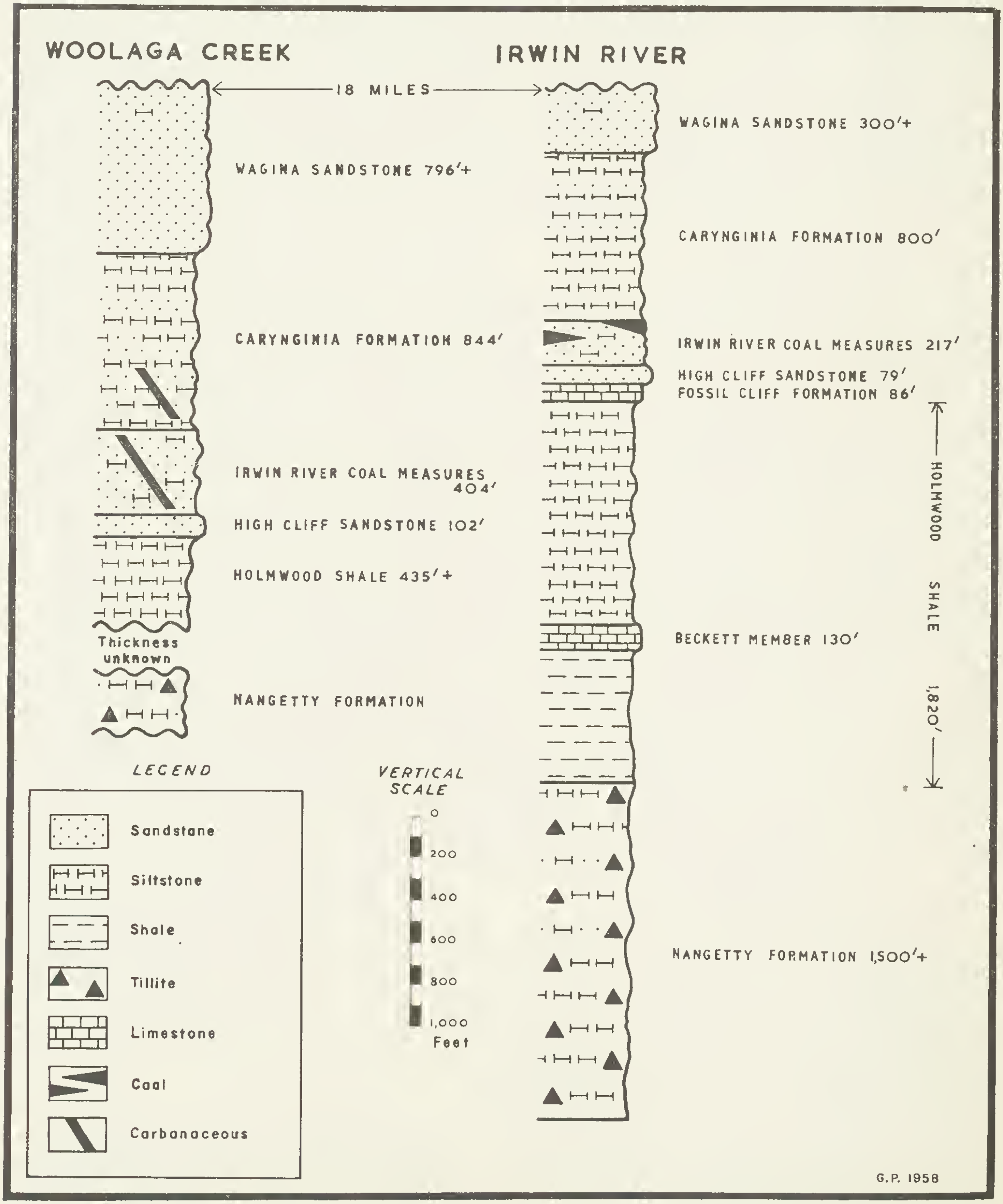

Fig. 2.—Columnar stratigraphic sections of the Permian System as developed in the Woolaga Creek and Irwin River areas. The Woolaga Creek section was measured in detail by the present author. The Irwin River section is based on thicknesses given by Clarke *et al.* (1951) and by McWhae *et al.* (1958).

of the Irwin River section. Also, the Beckett Member, which contains the large goniatite *Metalegoceras jacksoni* in the Irwin River area, does not crop out in the area under consideration. Both the Irwin River Coal Measures and the Wagina Sandstone attain considerably greater thicknesses at Woolaga Creek than in the type area. A new unit, the Woolaga Limestone Member of the Holmwood Shale, is proposed formally in this paper.

In summary, the Permian succession of the Woolaga Creek area (from top to bottom) is as follows:—

(6) *Wagina Sandstone:* Massively bedded, white and occasionally red sandstone and rare conglomerate, with plant-bearing intercalations of siltstone and shale near the top.
Thickness: 796 feet (plus).

(5) *Caryngినia Formation:* Predominantly grey and black jarositic siltstone, with interbedded yellow, reddish-brown and white sandstones and siltstones; "dumped" erratic boulders occur at the base.
Thickness: 844 feet.

(4) *Irwin River Coal Measures:* Interbedded very fine to coarse-grained sandstones, siltstones, and claystones containing abundant plant fossils.
Thickness: 404 feet.

(3) *High Cliff Sandstone:* Massively bedded white sandstone and rare conglomerate. In the basal part, marine fossils occur in lenses of red-brown ferruginous sandstone.
Thickness: 102 feet.

(2) *Holmwood Shale:* Grey clayey siltstone containing abundant jarosite and gypsum, with thin, lenticular beds of limestone. The *Woolaga Limestone Member* contains a rich marine fauna, whereas the other limestone beds are sparsely fossiliferous.
Thickness: 435 feet (plus).

(1) *Nangetty Formation:* Yellow siltstone and fine-grained silty sandstone, often containing pebbles, cobbles and boulders of gneiss, quartzite, chert and dolerite.
Thickness: Indeterminable.

The strata are believed to fall entirely within the Sakmarian and Artinskian Stages of the Permian System.

Epi-Permian

Superficial deposits overlie the Permian strata in many parts of the Woolaga Creek area. They occur on both lowlands and uplands and rarely attain a thickness exceeding 35 feet. The age of these deposits, apart from being obviously post-Permian, is not known.

(i) *Victoria Plateau Beds.*—These rocks were originally termed the "Plateau Beds" by Woolnough and Somerville (1924) and were later referred to as the Victoria Plateau Beds by Fairbridge (1952) and Johnson *et al.* (1954).

The Victoria Plateau Beds have only minor and restricted occurrence in the Woolaga Creek area. Lithologically, they are not unlike the Wagina Sandstone, and consist of massively bedded, medium-grained, white sandstone, which is sometimes mottled red. The beds are apparently horizontal and rest unconformably on the Permian strata. They are affected by lateritization. Outcrops of the Victorian Plateau Beds are to be seen at various places high on the peripheral breakaways of a large tableland in the north-western part of the area. Typical outcrops occur at (604872), (613866), (618865), and (606866).

The age of the Victoria Plateau Beds has always been conjectural owing to the apparent absence of fossils, and various authors have considered them to be of either Jurassic or Tertiary age.

(ii) *Duricrust and Sand-Plain.*—The surface of the Victoria Plateau is marked by a hard, horizontal capping of duricrust, frequently overlain by sand, on the flat-topped hills and tablelands in the area. This resistant surface gives rise to the familiar breakaway topography, and its veneer of quartz sand supports the usual low sand-plain scrub. The duricrust is mainly lateritic, but in several localities a highly siliceous variety ("billy") is developed. The process of laterization has caused a general hardening, leaching and colour mottling of the underlying Permian strata to a depth of 30 feet or more below the upper ferruginous, concretionary zone.

(iii) *Travertine.*—Travertine (or caliche) has been observed as a sporadically developed surface capping on both the Permian and Archaean terrains, around the uppermost reaches of Woolaga Creek. An extensive outcrop occurs in the vicinity of (668809) where large, horizontally disposed slabs of this white, lime-rich rock are exposed along the banks and in the bed of Woolaga Creek. The ridge of travertine, cropping out along the Darling Fault line at (679799), has been noted above. On the Darling Plateau, about three miles east of Ebano Spring, there is another large outcrop of travertine, forming a low bouldery mound, 200 yards south of the Mingenew-Morawa road.

(iv) *Consolidated Alluvium.*—Superficial deposits of reddish, ill-sorted conglomerates and coarse-grained sandstones are exposed in some places along the watercourses. They contain laterite pebbles, together with fragments of Permian and Archaean rocks, and are loosely cemented by ferruginous clay. These beds represent lithified river alluvium.

Permian Succession

Nangetty Formation

This formation was originally termed the "Nangetty Glacial Formation" by Clarke *et al.* (1951) and has since been amended to its present title by P. E. Playford and S. P. Willmott (in McWhae *et al.* 1958). The type locality is in the Nangetty Hills in the Irwin River area, where the formation comprises a poorly exposed sequence of tillite, boulder beds (containing many striated and faceted erratics), sandstones, conglomerates, siltstones and shales, and attains a thickness of about 1,500 feet.

The Nangetty Formation crops out in the extreme south-western part of the area studied. As in the Irwin River area, exposures are poor and it was not possible to measure a stratigraphic section or to delineate the relationship with the overlying Holmwood Shale. The formation consists of poorly sorted yellow siltstone and fine-grained silty sandstone, often containing pebbles, cobbles and boulders of gneiss, quartzite, chert and dolerite up to $2\frac{1}{2}$ feet in diameter. These weather out readily as a superficial gravelly accumulation. The dip of the strata is indeterminable owing to their massive nature; however, they appear to be approximately horizontal.

To the east of the Woolaga Creek area, there are several prominent patches of erratic boulders representative of this formation. Farther south, in the Yandanooka area, the Nangetty Formation rests unconformably either on Archaean gneiss or on the Yandanooka Group of Proterozoic or early Palaeozoic age. In the Irwin River area, the formation is conformable with the overlying Holmwood Shale.

The glacial origin of the Nangetty Formation was first postulated by Campbell (1910) on the evidence of the striated boulders, and has been confirmed by subsequent workers. P. E. Playford and S. P. Willmott (in McWhae *et al.* 1958) discovered varved shales in the formation in the Mullewa district, pointing to the fact that it is at least partly terrestrial.

In the Woolaga Creek area the Nangetty Formation appears to be unfossiliferous. Elsewhere, the only fossils obtained from the formation are pollen grains and spores from the Kockatea Creek bores in the Eradu district. These suggest a Sakmarian age for at least part of the Nangetty Formation (McWhae *et al.* 1958).

Holmwood Shale.

(i) *Stratigraphy.*—The Holmwood Shale was named by Clarke *et al.* (1951) after Holmwood pastoral station in the Irwin River area, on which the formation has extensive development. P. E. Playford and S. P. Willmott (in McWhae *et al.* 1958) nominated Beckett's Gully as the type section. These authors measured a thickness of 1,820 feet in this locality. Included in their section is the Beckett Member which they proposed as a unit of limestone beds occurring 630 feet above the base of the Holmwood Shale. Within the Beckett Member is the biostratigraphically important band containing the goniatite *Metalegoceras jacksoni.*

In the distance of 18 miles from the type section to the Woolaga Creek section, the Holmwood Shale exhibits little facies variation—the lithological similarities are marked between the two localities, although along Woolaga Creek only the upper part of the formation is exposed.

The reference section along Woolaga Creek, commences at (617819) and continues to (629829). The following is a description of this section.

High Cliff Sandstone (102 feet)

Holmwood Shale (435 feet +):

Unit	Thickness feet
11. Siltstone, dark grey weathering pale grey and brown, clayey; contains abundant yellow jarosite as bands, small nodular concretions and irregular masses together with less frequent layers and concretions of gypsum which is often associated with alunite. Plates of gypsum (selenite) up to $1\frac{1}{2}$ feet in diameter and $\frac{1}{2}$ inch thick were noted.	89
10. Limestone, dark grey weathering pale grey, hard, dense. Bouldery outcrop.	1
9. Siltstone, as in unit 11. Sporadic outcrop	8
8. Limestone, grey weathering pale grey, hard, dense; thin section showed the presence of scattered pyrite, also rare microfossils including calcareous spicules, indeterminate foraminifera and woody plant material with well-preserved cellular tissue. Bouldery outcrop	2
7. Siltstone, as in unit 11. Sporadic poor outcrop.	81
6. *Woolaga Limestone Member* (proposed herein). Limestone, grey weathering pale grey, hard, dense; vugs of chalcedony and of recrystallized calcite are common; contains a rich fauna including the small goniatites *Metalegoceras campbelli* and *Uraloceras irwinense*, together with crinoids, nautiloids, brachiopods, pelecypods, gastropods, conulariids and serpulids; the fossils are often silicified. Bouldery outcrop	3
5. Siltstone, as in unit 11. Poor outcrop	10
4. Limestone, grey weathering pale grey, hard, dense; rare microscopic spicular material (as in unit 8) was seen in thin section. Bouldery outcrop.	3
3. Siltstone, dark grey weathering pale grey and brown, clayey, jarositic, rarely gypseous. Sporadic poor outcrop.	80
2. Limestone, grey weathering pale grey, hard, dense, abundant clear recrystallized calcite. Bouldery outcrop.	1
1. Siltstone, as in unit 3. Sporadic poor outcrop.	157 +

Base of formation not exposed.

The Holmwood Shale occurs in the western part of the Woolaga Creek area. Scattered, poor exposures are characteristic, and are limited to breakaway slopes and to the more deeply incised watercourses. The formation consists predominantly of grey, clayey siltstone containing, as secondary minerals, abundant jarosite and gypsum and some alunite.

As stated by Clarke *et al.* (1951), the jarosite and alunite have almost certainly resulted from the chemical breakdown of pyrite or marcasite in the original sediment. These authors considered that the gypsum could have originated only as a primary precipitate during sedimentation, and claimed to have found some primary bands of the mineral. However, a more probable explanation is that the gysum also is secondary, and could have resulted from a reaction between primary calcium carbonate and sulphuric acid produced by the oxidation of the pyrite (or marcasite) in the sediments.

A good outcrop of gypsum, associated with alunite, is in a small watercourse at (636811), where the minerals occur as bands and irregular masses in jarositic Holmwood Shale. Grey, concretionary limestone is present also at this locality.

Several large boulders of Precambrian rock up to 5 feet in diameter, and possibly of glacial origin, were noted in cultivated country around (644796).

A striking feature of the Holmwood Shale is the presence of thin bands of limestone, which become particularly frequent towards the top. Some of these may be merely large, irregular concretions. They outcrop characteristically as lines of loose boulders consisting of hard, dense, crystalline limestone, which is grey, weathering to pale grey. Usually they can be traced only for a limited distance along the strike. This fact, together with their general distribution as shown by field mapping, points to lenticularity.

The most continuous and significant of these limestones is a moderately richly fossiliferous band which can be traced for two and a quarter miles along the strike. Its fauna includes crinoids, brachiopods, pelecypods, gastropods, conulariids, nautiloids, serpulids and two small goniatites *Metalegoceras campbelli* and *Uraloceras irwinense,* which, according to Teichert and Glenister (1952), indicate a Sakmarian age. Serpulids are particularly abundant in the limestone in the vicinity of (636807). The Woolaga Limestone Member is the name proposed for this fossiliferous limestone band, which attains an approximate thickness of 3 feet, and occurs 181 feet below the top of the Holmwood Shale at lat. 29° 12′ 8″ S., long. 115° 39′ 6″ E.

Of the numerous other limestone beds distributed freely within the upper 280 feet of the Holmwood Shale two, occurring at (644808) and (597856), contain rare small gastropods, pelecypods and crinoid stems, whereas the remainder appear unfossiliferous. In thin section, however, these limestones are usually seen to contain microscopic calcareous spicules which are not abundant and which cannot be identified precisely, together with indeterminable organic matter and rare foraminifera. After both macroscopic and thin section study of specimens of limestones (apart from the Woolaga Limestone Member) throughout the Holmwood Shale, it was found that only two lenses were lacking in fossils of some description.

A general paucity, in both individuals and species, is characteristic, therefore, of the faunas present in the thin lenticular limestones of the Holmwood Shale, with the notable exception of the Woolaga Limestone Member.

Clarke *et al.* (1951) refer to a "serpulid reef limestone" found in 1949 by Mr. L. de la Hunty of the Geological Survey of Western Australia at a locality four and a half miles south-east of Mt. Budd. They state that "further surveys here (by Fairbridge) have proved the extension of these lenticular outcrops over four miles along the strike." This is the first reference in the literature to the limestone band here termed the Woolaga Limestone Member. As mentioned previously, the present author was able to trace the member for a distance of only two and a quarter miles.

The limestone was considered by Clarke and his co-authors to be identical with the limestone exposed at Macaroni Hill in the Irwin River area. It is doubtful, however, whether a valid correlation can be made between the Macaroni Hill occurrence and the Woolaga Limestone Member. Even if serpulids were a sound basis for correlation, they are abundant in reef-like proportions only in one part of the member (at 636807).

A fossiliferous limestone band was discovered in the Irwin River area on the 1949 excursion from the Geology Department of the University of Western Australia. According to Clarke *et al.* (1951), this band occurs about 550 feet below the top of the Holmwood Shale. It contains a marine fauna which includes the two small goniatites *Metalegoceras campbelli* and *Uraloceras irwinense,* which are present also in the Woolaga Limestone Member. Thus, since both these bands have a markedly similar fauna and both consist of hard, grey, chalcedonised limestone, it would appear that they can be correlated with some certainty.

The Beckett Member in the Irwin River area, which contains *Metalegoceras jacksoni,* does not crop out in the Woolaga Creek area.

As mentioned previously, the stratigraphic relationship of the Holmwood Shale with the underlying Nangetty Formation is not evident in the Woolaga Creek area, but it is probably a conformable one, as it is farther north, in the Irwin River area. The lenticular Fossil Cliff Formation, conformably overlying the Holmwood Shale in the Irwin River area, does not appear to be represented at Woolaga Creek. Here, the Holmwood Shale is overlain with apparent conformity by the High Cliff Sandstone.

McWhae *et al.* (1958) quote 1,820 feet as the thickness of the Holmwood Shale in the Irwin River area. At Woolaga Creek, the present author measured a thickness of 435 feet, which however cannot be compared with the Irwin River section, since base is not exposed.

(ii) *Biostratigraphy.*—The goniatite species, *Metalegoceras jacksoni, Metalegoceras campbelli* and *Uraloceras irwinense,* indicate that the Holmwood Shale is of Sakmarian age (Teichert and Glenister 1952). Dr. B. F. Glenister (personal communication) correlates *M. jacksoni* with faunal assemblage 4 (Ruzhencev 1952) of the lower Tastubian in the southern Urals, and consequently assigns the Beckett Member to the early part of the Sakmarian Substage. (Note that according to current Russian nomenclature, the Sakmarian Substage represents the upper part of the Sakmarian Stage proper, as distinct from the lower part which is termed the Asselian Substage). In a forthcoming paper on the Permian ammonoids of Australia, Dr. Glenister will assign *Metalegoceras jacksoni* and *Metalegoceras campbelli* to the typical Sakmarian genus *Juresanites,* on the basis of their primitive sutures.

Four samples of spoil derived from the Holmwood Shale were collected, one from each of four bores (mentioned previously under **Physiography**) in the Woolaga Creek area, which penetrate the upper part of this formation. These samples were submitted for palynological examination to Mr. B. E. Balme, who ascribed a Lower Permian age to their microflora.

The following information about the samples is contained in a written communication by Mr. Balme to the author.

"Sample 39247* yielded no recognisable spores or pollen grains but fairly diverse and basically similar microfloras were obtained from the other three samples (39248, 39249, and 39250). In none, however, were the plant microfossils well-preserved and precise identification of the individual spore and pollen specimens was often difficult. Poor preservation appears to be a characteristic of the microfloras from the Holmwood Shale not only in the Woolaga Creek area but also in the Irwin River area and in the Kockatea Creek district to the north of Mingenew. Probably this is due to the activities of anaerobic bacteria during the deposition of the Holmwood Shale.

"The following spore and pollen species were identified in the three productive samples:

Group Triletes
- *Punctatisporites gretensis* Balme and Hennelly.
- *Acanthotriletes tereteangulatus* Balme and Hennelly.
- *Acanthotriletes* n. sp.
- *Granulatisporites* n. sp. A.
- *Verrucosisporites pseudoreticulatus* Balme and Hennelly.

Group Zonales
- *Cirratriradites* cf. *splendens* Balme and Hennelly.
- *Cirratriradites* spp.
- cf. *Reinchospora* sp.

Group Precolpates
- *Marsupipollenites* sp.

Group Monocolpates
- *Entylissa cf. cymbatus* Balme and Hennelly.

Group Saccites
- *Nuskoisporites* sp.
- cf. *Sahnites* sp.
- ? *Sahnites* sp.
- cf. *Illinites* sp.
- *Lucckisporites limpidus* Balme and Hennelly.
- *Lucckisporites amplus* Balme and Hennelly.
- *Lueckisporites multistriatus* Balme and Hennelly.
- *Pityosporites* ? n. sp. A.
- *Vestigisporites* cf. *rudis* Balme and Hennelly.

"Occasional small spinose organisms, probably hystrichosphaerids, were also present, suggesting a marine or near-marine environment.

"Discussion: The Lower Permian age of this microfloral assemblage is attested by the presence of *Punctatisporites gretensis, Verrucosisporites pseudoreticulatus, Entylissa* cf. *cymbatus, Vestigisporites* cf. *rudis,* ? *Sahnites* sp. and the abundance of species of *Cirratriradites.* These forms all characterise the Greta Coal Measures in New South Wales, the Lower Coal Measures at Mersey, Tasmania and the Grant Formation in the Fitzroy Basin of Western Australia. Similar microfloras have also been found in sediments from the Lake Phillipson Bore, South Australia* and in the upper part of the Lyons Group in the Carnarvon Basin.

"The resemblance is particularly close between this assemblage and those from the Grant Formation in the Kimberley Downs 67-mile Bore and in the B.M.R. No. 3 water bore in the eastern part of the Fitzroy Basin. It is heightened by the presence in assemblages from the Holmwood Shale and the Grant Formation of the forms cf. *Reinchospora* sp. and cf. *Illinites* sp., neither of which has been found in separations from any other stratigraphical units."

Dickens (1957) has examined several specimens of the Woolaga Limestone Member, from which he identified *"Sanguinolites"* sp. and *"Dielasma"* sp. ind. He was unable to draw any conclusions regarding the correlation of this fauna but he does consider it distinct from the fauna in the overlying fossiliferous basal part of the High Cliff Sandstone.

Both Johnson *et al.* (1954) and particularly Clarke *et al.* (1951) refer to the presence of "dwarf" or "restricted" faunas in the limestones of the upper Holmwood Shale. However, Tasch (1953) in a lengthy paper on faunal dwarfism justifiably emphasises that before any fauna may be validly designated as "dwarf" or "depauperate," it is necessary to apply exhaustive criteria based on wide, intensive collecting, detailed descriptions of faunal elements, and ecological studies.

The statements of Clarke and Johnson and their respective co-authors concerning the supposed faunal dwarfing are not supported by any such detailed studies and hence may not be well-founded.

It is true that *Metalegoceras campbelli* and *Uraloceras irwinense,* with a conch diameter averaging 10 to 15 mm in diameter, are small, particularly in comparison with *M. jacksoni,* but the associated faunal elements in the Woolaga Limestone Member appear to be of normal dimensions. Teichert and Glenister (1952) remarked on the close similarity of immature stages of *M. jacksoni* with specimens of *M. campbelli* of corresponding diameters, and were aware of the possibility of *M. campbelli* being a stunted, juvenile development of *M. jacksoni* due to an unfavourable environment.

However, one of the specimens of *M. campbelli* (39070) collected by the present author from the Woolaga Limestone Member appears to negate this possibility, since at a shell diameter of 6 mm it exhibits a crowding of the adoral sutures, which is generally accepted as indicating maturity or geronticism in an ammonoid (Miller 1947, p. 18).

Two of the other limestones in the Woolaga Creek area contain small rare specimens of gastropods, pelecypods and crinoids which may be dwarfed.

(iii) *Environment of Deposition.*—There is little doubt that the Holmwood Shale accumulated in a marine environment of restricted circulation. Woolnough (1937, 1938) initiated

*Catalogue number in the collections of the Department of Geology, University of Western Australia.

* Balme, B. E. (1957).—Upper Palaeozoic microfloras in sediments from the Lake Phillipson Bore, South Australia. *Aust. J. Sci.* 20: 61-62.

the hypothesis that the formation was deposited in a barred basin, and although some details of his original theory are debatable, subsequent authors are in general agreement with the basic concept advanced.

In the Woolaga Creek and Irwin River areas, the Holmwood Shale contains abundant jarosite, together with gypsum and alunite. These three minerals are almost certainly of secondary origin, resulting from the breakdown of primary pyrite (or marcasite).

In outcrop, always considerably weathered, the Holmwood Shale is pale grey to greyish-black, and does not generally appear to be carbonaceous. However, spoil from bores in the area shows it to be black and appreciably carbonaceous.

Most black shales are believed to have accumulated under conditions of restricted circulation (Twenhofel 1950, p. 337). Under such conditions, iron sulphide is precipitated in the stagnant waters deoxygenated by the bacterial decay of organic matter; benthonic life is usually absent.

Thus, on the evidence of its barrenness of fossils, and its almost certain primary content of pyrite (or marcasite) and carbonaceous matter, the Holmwood Shale was deposited in a basin that did not communicate freely with the sea, i.e. a barred basin.

Woolnough (1937, 1938) maintained that the absence of fossils in the formation was due to the high salinity of the basin, resulting from a contemporary arid climate. According to him, the presence of *Metalegoceras jacksoni* (in the Beckett Member) was due to a single catastrophe such as a violent storm breaking over the bar. Clarke *et. al.* (1951) considered that the Holmwood Shale was deposited in a barred basin under cool climatic conditions, although they thought it probable that the sea became shallower and warmer in late Holmwood times with evaporation resulting in the primary precipitation of gypsum.

There is no need to invoke, and there is no evidence for, the prevalence of a hot arid climate, particularly when the likelihood is considered of the gypsum being secondary in origin. While excessive salinity could account for a restriction or absence of animal life, so equally could the toxic, reducing conditions of a barred basin. Erratic boulders in the Holmwood Shale in the area under consideration point to deposition by floating ice and hence to a cool climate.

The Woolaga Limestone Member records a brief, unique stage in the faunally unfavourable Holmwood history. It represents a time during which a normal marine fauna was able to establish itself in fairly quiet waters or in lime muds accumulating there. The fossil debris appears to be biocoenotic because there is little evidence of abrasion of the fossils and because of the presence of abundant serpulids. The matrix in which the fossils are enclosed was probably a fine, highly calcareous mud, which has, however, undergone profound diagenetic changes. These include intrastratal solution (producing vugs), authigenesis (resulting in reorganization of primary calcite) and diagenetic metasomatism (silicification).

The member was probably deposited under normal shallow-water, marine conditions. Waves and currents must have been sufficiently active to cause some penecontemporaneous erosion of the lime muds (as evidenced by intraformational pebbles and granules) and the dissociation of the crinoidal skeletons, and to provide sufficient aeration to fulfil the needs of a thriving invertebrate fauna.

The other limestones occurring stratigraphically above and below the Woolaga Limestone Member, are far less continuous and appear to represent similar, but more localized interludes of lime mud deposition. They were accompanied by few organisms—viz. sponges, foraminifera, gastropods, pelecypods and crinoids. Some of the limestones may be merely large irregular calcareous concretions. They have not been diagenetically altered to the same extent as the Woolaga Limestone Member.

The structural framework of the postulated barred basin, and its precise boundaries and dimensions, are rather obscure at present. To the north, the Greenough Block of the Northampton-Geraldton district, and the Carrandibby Range at the south-eastern end of the Carnarvon Basin, are both prominent occurrences of Archaean rocks. Furthermore, geophysical work has shown them to be connected by a belt of shallow basement (McWhae *et al.* 1958). Hence, the basin was probably landlocked to the north. The eastern boundary of the basin was marked by the Archaean complex to the east of the Darling Fault. However, any theories regarding the western and southern limits of the basin, and its connection to the open ocean, must be regarded, at this stage, as purely conjectural.

High Cliff Sandstone

(i) *Stratigraphy.*—Clarke *et al.* (1951) proposed the name High Cliff Sandstone for an unfossiliferous sandy sequence, which is well-exposed at High Cliff (on the North Irwin River), where the type section is located. According to P. E. Playford and S. P. Willmott in McWhae *et al.* (1958), the formation attains a thickness of 79 feet at the type locality.

An outstanding characteristic of the High Cliff Sandstone in the Woolaga Creek area is the presence of an abundant fauna of marine invertebrates in its basal part. A boulder bed, discovered in the middle of the formation, is another feature of interest. The High Cliff Sandstone is thicker along Woolaga Creek than in the type area.

The reference section along Woolaga Creek extends from (629829) to (632832). The following is a description of this section.

Irwin River Coal Measures (404 feet)

High Cliff Sandstone (102 feet):

Unit.	Thickness feet.
3. Sandstone, quartzose, argillaceous, white with occasional minor red mottling; predominantly medium- and fine-grained, less commonly coarse-grained; moderately to well-sorted; quartz grains subrounded; poorly bedded, rarely cross-bedded; indurated vertical joints common in variable directions; weathered surface ferruginized, pale brown in colour; sporadic bands up to 6 inches thick of white, very coarse-grained, ill-sorted sandstone and conglomerate; a	

boulder bed occurs 24 feet above the base of the unit as a rubbly outcrop of boulders, cobbles and pebbles of gneiss, quartzite, pegmatite, chert and silicified breccia, which are enclosed within a matrix of very coarse-grained sandstone; the thickness of this bed is about 5 feet; 58 feet above base of unit is a normal fault (exposed high on the north bank of Woolaga Creek at 632831) of indeterminate but probably not large displacement; the fault plane is silicified, striking at 137° with an north-easterly dip of 63°. Outcrop varies from loose boulders to cliff exposures 71

2. Sandstone, red-brown, ferruginous, feldspathic, fine- to medium-grained; fairly well sorted; sub-rounded to angular grains; massively bedded; ferruginous concretions up to 9 inches in diameter; many boulders fossiliferous, some of them richly so, containing brachiopods, pelecypods, gastropods, bryozoans and corals; fossils ferruginized. Bouldery outcrop 27
1. Sandstone, pale yellowish-grey, fine-grained, silty, micaceous, poorly bedded; thin band of brown ferruginous sandstone at base of unit 4

Holmwood Shale (435 feet +).

As described above, the fossiliferous ferruginous part of the High Cliff Sandstone crops out as loose boulders in the reference section along Woolaga Creek. However, in the eroded track at (632826), adjacent to the site of the demolished "Glendevon" homestead, the fossiliferous sandstone occurs as six thin, red-brown, lenticular beds intercalated within the fine- to medium-grained white sandstone which is characteristic of the bulk of the formation. This basal part of the High Cliff Sandstone crops out along the strike only as boulders of the ferruginous, fossiliferous sandstone on the western slope of the cuesta—immediately south of the eroded track and also, farther north, between the same track and Woolaga Creek. It is apparent, therefore, that the ferruginous, fossiliferous sandstone is more resistant to erosion than the white sandstone with which it is interbedded. The prominent cuesta probably owes its form to this resistant basal part of the High Cliff Sandstone immediately overlying the much softer Holmwood Shale, and it is noteworthy that the fossiliferous lithology is practically unknown beyond the extent of this striking landform. At (626833), the most northerly expression of the cuesta, fossils are less frequent in the boulders, which are also less ferruginous than farther south. The fossiliferous High Cliff Sandstone has been traced for one and a quarter miles along the strike.

Elsewhere, at (596864) and at (651806), the basal part of the formation consists of unfossiliferous, white sandstone, although a precise contact with the Holmwood Shale is not exposed.

The question arises: is the fossiliferous, ferruginous sandstone simply a southerly facies variant of the richly fossiliferous Fossil Cliff Formation of the Irwin River area, or may it be validly assigned to the basal part of the High Cliff Sandstone?

Fairbridge (1952) considered that this fossiliferous sandstone at Woolaga Creek and also the "Mingenew Beds" (now elevated to formation status in McWhae *et al.* 1958), cropping out on Erregulla Springs property near Mingenew, were equivalents of the Fossil Cliff Formation. However, Fairbridge does not put forward any evidence for his correlation.

Johnson *et al.* (1954), while including the fossiliferous sandstone at Woolaga Creek in the High Cliff Sandstone, were aware of the possibility that its contained fauna may be equivalent to that of the Fossil Cliff Formation.

McWhae *et al.* (1958), without explanation or discussion, assign the fossiliferous unit in question to the base of the High Cliff Sandstone.

In addition to the fact that the actual fossiliferous facies is sandy, it is intercalated within the white sandstone, typical of the High Cliff Sandstone in both the Woolaga Creek and Irwin River areas. Thus, an assignment of the unit in question to the High Cliff Sandstone is indicated.

Further, Dickins (1957) believes that the Woolaga Creek fauna contains forms that are younger than those from the Fossil Cliff Formation.

If the equivalent of the Fossil Cliff Formation is indeed absent from the Woolaga Creek area, one might expect to find here a disconformity between the Holmwood Shale and the High Cliff Sandstone. However, the relationship between the two formations appears to be one of conformity at both exposures of the contact (629829 and 632826). A significant point in this connexion is that, in the type area, the Fossil Cliff facies is rather lenticular and has lithological similarities with the underlying Holmwood Shale. Indeed, Johnson *et al.* (1954) rejected the Fossil Cliff Formation as a valid formation, and included it within the Holmwood Shale. Thus, it could be that the Fossil Cliff Formation, where present, is simply a rather large fossiliferous lenticle in the upper part of the Holmwood Shale, representative of a period during which conditions favoured the establishment of a prolific marine fauna. Farther south, however, in the Woolaga Creek area, the contemporary environment could have been unfavourable for abundant life, and as a result the Fossil Cliff Formation could be represented here by comparatively barren Holmwood Shale. Under these circumstances, a conformable relationship between the Holmwood Shale and the High Cliff Sandstone would not be unexpected.

On the evidence available, therefore, it is justifiable to include the fossiliferous sandstone within the basal part of the High Cliff Sandstone.

Current opinion (based on the work of Mr. J. M. Dickins) is that the Mingenew Formation is the youngest unit in the Permian succession of the Irwin River area (McWhae *et al.* 1958). The fauna of the formation is Artinskian in age.

A conformable contact between the High Cliff Sandstone and the overlying Irwin River Coal Measures is exposed in a small creek in the reference section at (632832). At this point, a minor strike fault with east-block-down movement has slightly affected both the basal Irwin River Coal Measures and the underlying

High Cliff Sandstone. In three localities (638819), (597865) and (613854) the two formations have been brought into abutment by faulting. At (638819), a prominent ferruginized fault zone is exposed on the breakaway slope. On the west side of the fault, medium- and coarse-grained, white and red sandstones (High Cliff Sandstone), exhibiting minor cross-bedding, dip at 17° to the north-east. On the eastern side, sediments of the Irwin River Coal Measures consisting of pure white, well-bedded siltstones and fine- to medium-grained sandstones have a north-easterly dip of 30° adjacent to the fault zone; 55 feet farther east their attitude has flattened out to a dip of 8° in the same direction. There was some doubt whether these latter sediments belonged to the Irwin River Coal Measures as they look rather similar to the adjacent High Cliff Sandstone, but the chocolate siltstones underlying them in gullies below the breakaway are typical Coal Measures lithology. Thus, this fault, with a trend of 168° has an east-block-down movement. At (597865), a fault occupies a narrow elongate topographic low between an outcrop of cross-bedded, white High Cliff Sandstone on the northern slope of a small hill, and a breakaway, immediately north of this hill, which exposes typical plant-bearing sediments of the Irwin River Coal Measures on its western point. On two small adjacent low rises at the immediate base of this breakaway, the sandstones, carbonaceous shales and siltstones of the Coal Measures show strong evidence of upturning against the fault with an average north-north-easterly dip of 40°. The exposure at (613854) is poor, but appears to represent another fault contact between the two formations.

Along the reference section described above, the measured thickness of the High Cliff Sandstone is possibly somewhat lower than the true thickness on account of the effect of strike faulting. Thus, the fault at (632831) would have the effect of lessening the exposed thickness of the formation. However, the figure given for the section, viz. 102 feet, is less than half that stated by Johnson *et al.* (1954) for the thickness of the formation at Woolaga Creek, and the present author finds their figure (250 feet) quite untenable.

A water bore, sited at (638821) close to the top of the High Cliff Sandstone, penetrated 116 feet of this formation before passing into the Holmwood Shale, and was abandoned at a depth of 124 feet. Two other unsuccessful bores for water at (635824) and (654805) passed through 106 feet and 68 feet respectively of High Cliff Sandstone before encountering the Holmwood Shale in which they were abandoned at respective depths of 108 feet and 80 feet. As the dip of the High Cliff Sandstone is only of the order of 6°, the above vertical depths closely approximate to stratigraphical thicknesses.

Apart from the presence of marine fossils in its basal part and of the boulder bed stratigraphically higher in the section, the exposures of the High Cliff Sandstone in the Woolaga Creek area are lithologically similar to those of the type area. Characteristically, the formation consists of medium-, fine-, and sometimes coarse-grained white sandstone, which contains occasional conglomeratic lenses. Cross-bedding is less a feature of the High Cliff Sandstone at Woolaga Creek than in the Irwin River area.

(ii) *Biostratigraphy.*—Specimens from the fossiliferous, basal 30 feet of the High Cliff Sandstone, collected by the present author and by parties of senior students from the Department of Geology, University of Western Australia, were examined recently by Mr. J. M. Dickins of the Bureau of Mineral Resources, Canberra.

The results of his studies of the brachiopods, pelecypods and gastropods—which are the dominant groups in the fauna—are embodied in an unpublished report (Dickins 1957).

The following identifications are listed in this report:

Brachiopoda
- *Linoproductus (Cancrinella)* cf. *lyoni* (Prendergast) 1942.
- *Linoproductus (Cancrinella)* sp.
- *Linoproductus (Cancrinella)* sp. ind.
- *Aulosteges* cf. *ingens* Hosking 1931.
- *Aulosteges* sp. ind.
- *"Chonetes"* sp.
- *Permorthotetes* sp.
- *"Dielasma"* sp. nov. A.
- *"Dielasma"* sp. nov. B.
- "Martiniopsis" sp. A.
- *Phricidothyris* ? sp.
- *Cleiothyridina* sp.
- *Cleiothyridina* sp. ind.
- *Spiriferidae* sp. nov.
- *Neospirifer* sp. nov. A.
- *Neospirifer* sp. nov. A. ?
- *Neospirifer* sp. nov. B.
- *Neospirifer* sp. ind.

Pelecypoda
- *Parallelodon* sp. nov.
- *Parallelodon* sp. ind.
- *Astartila* ? sp. nov.
- *Astartila* ? sp. ind.
- *Stutchburia* cf. *variabilis* Dickins, in press.
- *Stutchburia* ? sp. ind.
- *Atomodesma* cf. *mytiloides* Beyrich 1865.
- *Schizodus* sp.
- *Oriocrassatella* cf. *stokesi* Etheridge Jnr. 1907.
- *Streblochondria* sp. ind.
- *Streblochondria* ? sp.
- *Aviculopecten* cf. *tenuicollis* (Dana) 1847.

Gastropoda
- *Bellerophon* sp.
- *Bellerophon* sp. ind.
- *Baylea* ? sp.

Dickins notes the distinctiveness of this fauna from that of the Woolaga Limestone Member of the Holmwood Shale. Further, he considers that the High Cliff Sandstone fauna as a whole is distinct from both the fauna of the Mingenew Formation and the fauna from Carynginia Gully, which was assigned recently to the Fossil Cliff Formation by Dickins and Thomas (1957).

Dickins states that the fauna of the High Cliff Sandstone contains fossils which are younger than those from the Fossil Cliff Formation, and concludes that it is probably representative of a marine horizon intermediate between the Callytharra Formation (equivalent to the Fossil Cliff Formation) and the Madeline Formation which are both developed in the Carnarvon Basin.

Thus the High Cliff Sandstone is of Artinskian age.

(iii) *Environment of Deposition.*—Factors which are important when synthesizing the de-

positional environment of the High Cliff Sandstone are as follows:—

1. The fossiliferous, basal part of the formation, though lenticular, indicates a marine environment during at least early High Cliff times.

2. Although sorting may be classed as only moderate in its lower part, the High Cliff Sandstone is in general notably well-sorted. This degree of size-sorting is suggestive of the rather prolonged activity of waves and currents as in a near-shore marine environment. Stetson and Upson (1937, p. 57) state an average coefficient of sorting of 1.45 for well-sorted, near-shore sediments; and in fact the sorting coefficients obtained for two typical specimens of High Cliff Sandstone (39279 and 39280) are remarkably close to this value (1.44 and 1.41 respectively).

3. Sediments of similar lithology and stratigraphic position occur elsewhere in the Permian of Western Australia. These formations, with which the High Cliff Sandstone is correlated, are the Moogooloo Sandstone of the Carnarvon Basin and the Poole Sandstone of the northern part of the Canning Basin. Such a laterally extensive sequence of well-sorted quartzose sands could be reasonably ascribed only to the shallow-water marine conditions of a stable shelf. It is significant also that McWhae *et al.* (1958) report the presence of a marine fauna of brachiopods and bryozoans in the basal part of the Moogooloo Sandstone.

Although inconclusive in themselves, these factors taken together constitute strong evidence that the High Cliff Sandstone was deposited in a shallow-water marine environment.

The presence of allogenic feldspar in the basal part and its absence higher in the formation (where quartzose sandstones predominate) suggests a decrease in relief of the hinterland concomitant with the advancement of High Cliff time.

The ferruginization of the lenticular, fossiliferous sandstone is almost certainly an effect of lateritization. It appears that, in Western Australia, lime-bearing sediments are particularly susceptible to replacement by iron. P. E. Playford (1954) has described the pronounced effect of lateritization on the Newmarracarra Limestone which occurs in the Geraldton district. Similarly, the fossiliferous High Cliff Sandstone is completely leached of calcium carbonate, with the fossils represented only by haematitic moulds and with the matrix of the rock heavily impregnated with iron. It would appear that, prior to lateritization, these fossiliferous lenticles consisted of calcareous, argillaceous sandstone.

Irwin River Coal Measures

(i) *Stratigraphy*.—The formation name Irwin River Coal Measures was first proposed by Clarke *et al.* (1951) for the succession of "shales and sandstones with some interbedded coal seams" resting conformably between the High Cliff Sandstone and the Caryngingia Formation. The type section is along the North Irwin River. Subsequently the usage of Clarke and his co-authors was modified by Johnson *et al.* (1954), who encountered difficulties in separating the Irwin River Coal Measures from the Caryngingia Formation particularly in the Woolaga Creek area. Johnson and his co-authors proposed to combine the two units into the one formation, which they termed the Irwin River Coal Measures.

P. E. Playford and S. P. Willmott in McWhae *et al.* (1958) reaffirm the validity of the nomenclature of Clarke *et al.* (1951), and record a thickness of 217 feet for the type section of the Irwin River Coal Measures.

Although the boundary between the Irwin River Coal Measures and the Caryngingia Formation is transitional in the Woolaga Creek area, the present author considers that the two units are sufficiently distinctive in this area to justify their recognition as separate formations. A satisfactory contact was discovered at (641832). The author cannot agree with Johnson *et al.* (1954, p. 49) that the two units were deposited in a similar environment.

In the Woolaga Creek area, the Irwin River Coal Measures are notably less carbonaceous, and attain a greater thickness than in the type locality.

The Woolaga Creek reference section of the Irwin River Coal Measures commences at (632832) and continues to (641832). The following is a description of this section.

Caryngingia Formation (844 feet)

Irwin River Coal Measures (404 feet):

Unit	Thickness Feet
28. Composite lithological unit. Sandstone, mottled red, grey and yellow, ferruginous, micaceous, fine- to medium-grained, friable, moderately sorted, commencing at 6 feet above base of unit are lenticular intercalations of siltstone, grey-black, carbonaceous (increasing towards top) and of siltstone, red and yellow, ferruginous, resistant; an ill-sorted lenticular band of conglomerate occurs 20 inches below the top of the unit; the uppermost part of the unit comprises a resistant 4-inch band of irregularly intercalated yellow and grey, medium-grained sandstone, bright red siltstone and black, carbonaceous, clayey siltstone; weathered cobbles and boulders occur within the upper 6 inches of the unit.	9
27. No outcrop.	16
26. Interbedded sandstone, pale brown, fine-grained, and siltstone, yellow, purplish-red, brown and chocolate, ferruginous, jarositic. Rubbly outcrop.	1
25. Sandstone, yellow to brownish-yellow, micaceous, ferruginous, fine- to medium-grained, friable, moderately sorted, poorly bedded, sometimes cross-bedded; some relatively resistant horizons of sandstone, brown, ferruginous, micaceous; irregular thin intercalations of carbonaceous material (plant remains), and red-brown, fine-grained sandstone and siltstone as resistant bands up to 2 inches thick; the upper 10 feet of the unit is non-carbonaceous; rounded erratic boulders up to $2\frac{1}{2}$ feet in diameter occur 3 feet above base and elsewhere sporadically in the unit.	20
24. Rhythmically alternating sequence. Predominantly siltstone, chocolate, micaceous carbonaceous, shaly, rich in plant fossils; intercalated with more or less regular bands (up to 4 inches thick) of sandstone, yellow-brown, ferruginous, micaceous, quartzose, very fine to medium-grained, friable, poorly sorted, some plant fossils, and sandstone, pale grey, mica-	

ceous, quartzose, fine-grained, friable, well-sorted; unit becomes slightly less carbonaceous, less silty, and more ferruginous towards top; prominent joints trending 10° with a westerly dip of 80°, and 90° with a southerly dip of 80°. 6
Unit 24 and the lower part of unit 25 exhibit large-scale slumping phenomena (Plate 1, 2). This is particularly well shown by the broadly undulating boundary between the two units. Individual beds within the slumped strata show a high degree of contortion.

23. No outcrop. 58
22. Siltstone, brownish-grey, micaceous, ferruginous, friable, thin-bedded, cross-bedded. 8
21. Siltstone, black, clayey, ofter highly carbonaceous, with thin yellowish sandy ferruginous bands; grading up into a less carbonaceous, ferruginous siltstone, brownish-grey with thin black bands, friable; plant fossils; thin-bedded with cross-bedding on minor scale. .... $6\frac{1}{2}$
20. Sandstone, grey and yellow, ferruginous, fine-grained, friable. .... $1\frac{1}{2}$
19. Sandstone, greyish-white, chocolate and yellowish-brown, silty, micaceous, ferruginous, very fine grained, friable, thin-bedded; intercalated irregularly with siltstone, greyish-black and chocolate, carbonaceous, micaceous, friable, plant fossils; brown ferruginous concretions (up to 1 inch in diameter) in upper part; $2\frac{1}{2}$-inch band of friable, highly weathered, black coaly material constitutes the uppermost part of unit; outcrop has white, salty incrustation. 6
18. No outcrop. 6
17. Siltstone, yellow, micaceous, ferruginous, friable, thin-bedded; passing into claystone, black, red and white, carbonaceous, ferruginous, massively bedded, ferruginous bands resistant and concretionary. 3
16. Claystone, red and white, very soft, massively bedded, containing plant fossils, with thin lenses of black, carbonaceous siltstone. .... $2\frac{1}{2}$
15. Sandstone, white, quartzose, coarse-grained, friable, moderately sorted, sub-angular grains, cross-bedded; contains small, irregularly shaped fragments of grey siltstone. 6
14. Claystone, grey, red and white, carbonaceous, ferruginous, friable, massively bedded, rich in plant fossils. .... $2\frac{1}{2}$
13. Siltstone, alternating cholocate-grey and yellow-brown, shaly, carbonaceous and ferruginous, thin-bedded, containing plant fossils. .... $10\frac{1}{2}$
12. Sandstone. greyish-white, micaceous, fine-grained, friable, moderately sorted, cross-bedded. .... $2\frac{1}{2}$
11. Shale, chocolate-grey, micaceous, carbonaceous, thin-bedded, containing plant fossils; thin intercalated bands of siltstone, yellow, red and brown, ferruginous, resistant, rich in plant fossils; 4 feet above base of unit is a 4-inch band of sandstone, white, feldspathic, coarse-grained, poorly sorted, massively bedded, angular grains. 6
10. Sandstone, greyish-white with minor pale brown mottling, micaceous, fine-grained, friable, moderately sorted, poorly bedded; thin (up to 1 inch) bands of grey siltstone near top of unit. 3
9. Sandstone, greyish-white and pale yellow-brown, micaceous, ferruginous, fine-to very fine-grained, with intercalated silty horizons, cross-bedded, friable. 16
8. Shale, black, carbonaceous, thin-bedded, rich in plant fossils. 6
7. No outcrop. 18
6. Siltstone and sandstone, very fine-grained, grey, greyish-white and yellow, micaceous, friable, thin-to thick-bedded, plant fossils in many horizons; rare thin, lenticular, sandy bands. 61
5. Sandstone, very pale brown, feldspathic, coarse- to very coarse-grained, ill-sorted, angular grains, massively bedded; uppermost 8 inches of unit consists of siltstone, purplish-red, sandy, feldspathic, non-friable, poorly sorted, ripple-marked with long axes of ripple-marks trending 35°, forms a resistant slabby capping to unit. 7
4. Sandstone, yellow-brown, ferruginous, micaceous, very fine-grained, friable, cross-bedded. 8
3. No outcrop. 60
2. Sandstone, white, weathering pale brown, quartzose, medium- to fine-grained, friable, moderately sorted, sub-rounded grains, massively bedded, locally cross-bedded; minor thin (3-inch) bands of coarse sandstone. 37
1. Siltstone, greyish-black, carbonaceous, friable, thin-bedded, containing abundant plant fossils; thin intercalations of siltstone, yellow and brown, ferruginous, weathering to small thin slabs, and of sandstone, pale yellow and brown, medium- to coarse-grained, quartzose, friable, poorly sorted, often lenticular; at base of unit is a thin (3-inch) band of siltstone, reddish-brown, ferruginous, resistant, bearing plant fossils. 17

High Cliff Sandstone (102 feet).

The Irwin River Coal Measures in the Woolaga Creek area comprise a remarkably varied sequence of interbedded very fine to coarse-grained sandstones, siltstones and claystones containing plant fossils at many horizons. The sandstones are generally ill-sorted, frequently cross-bedded, occasionally ripple-marked, and are white, yellow, grey and red in colour. The siltstones and claystones are sometimes shaly, frequently micaceous, ferruginous and carbonaceous, with varying colours of white, grey, chocolate, yellow, brown, red and black.

Rapid lateral and vertical changes in lithology characterize the Irwin River Coal Measures, particularly in the lower part. Excellent exposures occur along Woolaga Creek and its tributaries in the general vicinity of (638834). Also, the formation is well-exposed along the breakaways at (643820), whereas farther south outcrops are intermittent and generally poor. To the north of Woolaga Creek, good outcrops occur on the northerly slopes of the mesa at (629837), and on breakaways north of Mt. Budd in the north-western part of the area.

The sequence is decidedly less carbonaceous than in the type area. Richly carbonaceous facies are restricted to two thin beds, each about 1 foot in thickness, which crop out on a subsidiary rise below the breakaway at (643820); and to a thin seam of coaly material (top of unit 19 of the reference section) in an undercut cliff exposure at (636835), a prominent bend in Woolaga Creek.

Plant fossils, mainly leaf impressions, occur abundantly throughout the formation. Good plant fossil localities include (634834), (632832), (629837), (632835), 635835), (636832), (639827), (643820), (638834) and (596866). The only other fossils found in the Irwin River Coal Measures were worm tracks occurring at (627845), where they form a ramifying network in reddish-brown, fine-grained sandstone.

The upper Irwin River Coal Measures show large-scale slumping along Woolaga Creek in the vicinity of (638834). This occurs in siltstones and fine-grained sandstones (units 24 and 25 of the reference section). The strata are broadly folded with resultant marked variations in strike (Plate 1, 2) and merge upwards into undeformed strata. Furthermore, there is extreme contortion of the laminae within individual beds of the slumped strata. Hence we have penecontemporaneous soft-sediment folding on both large and small scale.

Erratic boulders of gneiss, granite and quartzite occur in the upper Irwin River Coal Measures. These erratics are found on the east bank of Woolaga Creek at (639834) in unit 25 of the reference section. They are as much as 2½ feet in diameter and are not associated with boulder clay. Fairbridge (1952) noted the presence of "dumped" erratics in the Irwin River Coal Measures and concluded that they had been deposited from floating vegetation rather than from floating ice.

Ferruginous concretions occur in white siltstone and fine-grained sandstone in a creek at (621843). These sub-spherical bodies average 3 inches in diameter, and are composed of yellow-brown iron oxide, with a central core of finely oolitic jarosite and minor gypsum. They appear to be a product of weathering, resulting from the chemical decomposition of concretionary pyrite or marcasite.

Strike faults having small throws are fairly common. The most important are those, already described, which have thrown the High Cliff sandstone against the Coal Measures. Rather poorly exposed, lateritized siltstones of the Irwin River Coal Measures are deformed into a drag syncline within a distance of one quarter of a mile adjacent to the Darling Fault. This structure occurs in the south-eastern part of the area and is displayed exceptionally well by the air photographs.

The contact between the Irwin River Coal Measures and the underlying High Cliff Sandstone is conformable in the reference section. In two localities (641832) and (595873), the Irwin River Coal Measures are overlain transitionally and conformably by the Caryngınia Formation.

The Irwin River Coal Measures attain a thickness of 404 feet in the Woolaga Creek area. This is almost twice the thickness of the formation in its type area.

(ii) *Biostratigraphy.*—The plant fossils of the Irwin River Coal Measures are typical representatives of the Permian Gondwana flora. *Glossopteris* is the most abundant genus, and other genera identified by the author include *Sphenopteris, Sphenophyllum, Bothrodendron, Phyllotheca* and *Gangamopteris*. All of these genera have been recorded from the type area of the Irwin River Coal Measures (Clarke *et al.* 1951).

Palynological studies reported by McWhae *et al.* (1958) on the rich microflora present in the formation suggest an Artinskian age. These authors correlate the Irwin River Coal Measures with the Collie Formation of the Collie and Muja Basins.

(iii) *Environment of Deposition.*—The Irwin River Coal Measures are considered to represent a composite fluviatile and paludal deposit, which possibly accumulated as the topset component of a delta.

This mode of origin is suggested by the following attributes of the formation:—The remarkably rapid alternation of rock types and their individual lateral impersistence has already been discussed; this feature is characteristic of fluvial sediments. The abundance of plant material throughout and the absence of marine fossils is strong evidence for a continental environment of deposition. Added confirmation of this is found in the fact that the plant fossils are mainly well-preserved leaves, which obviously could not have survived much transportation and must therefore have been deposited close to their habitat. The large-scale cross-bedding and ripple-marking developed by the Irwin River Coal Measures are further characteristic of fluviatile deposits. Worm tracks present in the formation point to shallow-water conditions.

The typical yellow, brown and red colours of some of the strata are due to their content of trivalent iron compounds. A significant point in this connexion is that bore samples of the Irwin River Coal Measures are generally grey or black, and sometimes contain pyrite (Johnson *et al.* 1954, pp. 94-100). This suggests that the bright colours of the sediments in outcrop have probably resulted mainly from weathering processes. With abundant organic matter present in the depositional environment it is probable that conditions would have been favourable for the precipitation of iron sulphide, particularly in swamps on the flood plain. Furthermore, primary pyrite (or marcasite), when subjected to weathering, would readily decompose to form ferric compounds. Thus, although no marcasite or pyrite were found in outcrop, many of the sediments containing abundant plant impressions are also rich in ferric compounds. Some ferruginous concretions present in the formation appear to be pseudomorphous after pyrite or marcasite. On the other hand, some of the iron could have been deposited primarily as ferric hydroxide (limonite) and iron carbonate, together with the iron sulphide, under paludal conditions. It should also be mentioned that the red-brown colour of sediments lying close to the Victoria Plateau level may usually be attributed to the effects of lateritization.

The prevailing easterly dip is due to subsequent tectonism and is not a primary feature of the Coal Measures sediments, which must have been almost horizontal when deposited. Hence if the environment was deltaic, as is indicated, the sediments could only represent topset beds within this environment.

The upper part of the Irwin River Coal Measures has smaller scale cross-bedding and greater lateral and vertical persistence of strata, which are of somewhat finer grain. This seems to suggest a transition to shallow-marine or lagoonal conditions in late Coal Measures time. The interesting but problemati-

cal erratic boulders in the formation may have been deposited from either floating ice or floating vegetation.

The generally well stratified nature of the formation and its well-sorted sandy intercalations suggest that most of the sediment has been transported some considerable distance and distributed in successive layers over the delta. The rarity of conglomerate, or even conglomeratic sandstone, also indicates a distant source for the sediments, while the presence of fresh feldspar in the sandstones is evidence of fairly rapid erosion in the source area.

Carynginia Formation.

(i) *Stratigraphy.*—Clarke *et al.* (1951) originally termed this formation the "Carynginia Shale." However, as there is little shale in the unit, P. E. Playford and S. P. Willmott (in McWhae *et al.* 1958) have altered the name to Carynginia Formation. According to Clarke and his co-authors, the Carynginia Formation attains a thickness of 800 feet in the type locality, which is situated in Carynginia Gully, a tributary of the North Irwin River.

The Carynginia Formation appears to be more sandy and better exposed at Woolaga Creek than in the Irwin River area. It is interesting to note that, in both areas, erratic boulders occur in the basal part of the formation. The Carynginia Formation is somewhat thicker in the Woolaga Creek area than in the type area. Lithologically, the unit often resembles the Holmwood Shale.

The reference section in the Woolaga Creek area extends from (641832) to Red Hill (647838). The following is a description of this section.

Wagina Sandstone (796 feet +)

Carynginia Formation (844 feet):

Unit	Thickness Feet
7. Siltstone, chocolate-black weathering pale grey, jarositic, micaceous, clayey, thin-bedded; bands (up to 1 foot thick) of sandstone, white and grey, medium-grained, silty, fairly well sorted, rounded grains; thin intercalations of siltstone, yellow-brown, ferruginous, resistant.	84
6. No outcrop.	123
5. Composite lithological sequence, with small-scale slumping in lower part Interbedded siltstone, grey and chocolate-black, weathering pale grey, jarositic, micaceous, shaly, thinly to massively bedded; fine- to very fine-grained sandstone and siltstone, grey, yellow and red-brown, ferruginous, micaceous, friable and non-friable, locally cross-bedded, often fissile; where richly ferruginous, the sandstones and siltstones are very resistant to weathering and stand out as projecting ledges. Commencing 53 feet above base of unit are thin (9-inch), freely intercalated, often lenticular bands of sandstone, white, feldspathic, coarse-grained to conglomeratic, non-friable to friable, fairly well sorted, subrounded grains, massively bedded, often broadly ripple-marked. Striking differential compaction effects are seen with sandstone and associated siltstone. Seventy feet above base of unit is a prominent ½-inch band of ferruginous siltstone bearing worm tracks and oscillation ripple-marks; the ripple-marks have a wave length of 9 inches, amplitude of ½-inch, and trend 10°.	168
4. Siltstone, grey, chocolate-black and brown, jarositic, micaceous, clayey, friable, thin-bedded; minor thin intercalations of siltstone, red-brown, ferruginous, micaceous, resistant, weathering to small thin slabs; rare lenticular bands (up to 2 feet thick) of sandstone, pale brown and yellow, slightly ferruginous, medium- to coarse-grained, moderately sorted, rounded grains, massively bedded. Sporadic outcrop.	427
3. Sandstone, brown, pale grey and red, feldspathic, silty, fine- to very coarse- grained, well-sorted, subrounded grains, massively bedded; freely and irregularly intercalated with siltstone, chocolate-black weathering grey, jarositic, carbonaceous containing thin lenses of siltstone, red, ferruginous, resistant. Unit more more sandy in upper part.	9
2. Shale, chocolate-black, weathering grey, richly jarositic, carbonaceous, micaceous, silty, thin-bedded (0.5 cm.); with intercalated regular bands (up to 1½ inches thick) of siltstone, bright red and yellow-brown, ferruginous, resistant, composing about one-tenth of unit; also minor lenses of sandstone, red and yellow, ferruginous, medium- to coarse-grained, friable, poorly sorted, insignificant in upper part of unit.	28
1. Interbedded bands and lenses of siltstone, chocolate-black, richly jarositic, carbonaceous, micaceous, clayey, greasy feel, pungent odour when freshly cut, massively bedded; and sandstone, yellow-brown, ferruginous, medium- to fine-grained, friable, moderately sorted, massively bedded, less resistant than the siltstone. In upper part of unit is a lenticular band (with maximum thickness of 2 feet) of sandstone, mottled white, red and yellow, ferruginous, coarse-grained, friable, poorly sorted, massively bedded. Pebbles, cobbles and boulders of gneiss, granite and dolerite, often highly weathered, and with maximum diameter of 1.2 feet, occur in lower 4 feet of unit. "Dumping" is suggested by the fact that the bedding of the enclosing sediments curves below the boulders.	5

Irwin River Coal Measures (404 feet).

In the Woolaga Creek area, the Carynginia Formation consists predominantly of grey and black jarositic siltstones with interbedded yellow, reddish-brown and white sandstones and siltstones; "dumped" erratic boulders occur at the base. The jarositic siltstones are carbonaceous in the lower part of the formation and in places contain minor amounts of gypsum. Ripple-marking and rather small-scale cross-bedding are fairly common in the unit.

The Carynginia Formation is extensively developed and generally well exposed in the area under consideration. There are some particularly fine exposures along two large adjacent tributaries of upper Woolaga Creek in the south-eastern part of the area. Also, where these two tributaries enter Woolaga Creek (at 655821), the west bank of the latter constitutes an impressive cliff section extending almost continuously along the strike for three-eighths of a mile. The narrow elongated mesa at (623852), immediately north of the Mingenew-Morawa road, is composed of

Caryngina Formation. An excellent exposure of the typical greyish-black, richly jarositic siltstones of the formation occurs on the northern point of this hill. The deep erosion gullies in the vicinity of (638835) provide numerous fresh exposures of the formation. The reference section, described above, comprises the most nearly complete exposure of the Caryngina Formation in the area.

In the south-eastern part of the Woolaga Creek area, the strike of the sediments is deflected through a maximum angle of 145° within one half a mile marginal to the Darling Fault, so that here the Caryngina Formation abuts against the Precambrian complex.

Contrasting with its transitional relationship with the underlying Irwin River Coal Measures, the Caryngina Formation is overlain abruptly, but conformably, by the Wagina Sandstone. Indeed, the contact between the Caryngina Formation and the Wagina Sandstone is the most readily mappable geological boundary in the area. It is well-exposed near the top of Red Hill (Plate 1, 3) and at several points along a breakaway immediately to the north. The trend of the contact at these localities is 158° However, in the south-eastern part of the area the same contact is markedly deflected in conformity with the change in strike of the sediments noted above. Thus the trend of the Wagina Sandstone-Caryngina Formation boundary is 43° along the southern escarpment at (661832), adjacent to the Darling Fault.

The thickness of the Caryngina Formation is 844 feet in the Woolaga Creek reference section, which is 44 feet greater than the type thickness in the Irwin River area.

(ii) *Biostratigraphy.*—The Caryngina Formation is practically unfossiliferous. Worm tracks are sometimes present in the strata, and a single indeterminable cast of a pelecypod (specimen 39303) was found in greyish-white, sandy siltstone cropping out at (653823).

The Permian age of the Caryngina Formation is unquestionable by virtue of its stratigraphical position between the Irwin River Coal Measures and the Wagina Sandstone, both of which contain diagnostic Permian plant fossils. McWhae *et al.* (1958) ascribe an Artinskian age to the Caryngina Formation without presenting any conclusive biostratigraphical evidence.

(iii) *Environment of Deposition.*—The similarity between the Caryngina Formation and the Holmwood Shale indicates a similar environment of deposition for the two formations.

The Caryngina Formation contains abundant jarosite and rare gypsum and is carbonaceous, particularly in the basal part. All these features, as with the Holmwood Shale, suggest that the formation accumulated under conditions of restricted circulation, i.e., within a barred basin.

The depositional environment was almost certainly marine. This is indicated by the presence of hystrichosphaerids (McWhae *et al.* 1958) and of a single pelecypod, discovered by the present author. The relatively uniform lithology of the Caryngina Formation and its marked resemblance to the marine Holmwood Shale also suggest marine conditions.

The erratic boulders in the basal part of the formation pose the familiar problem as to whether they have been deposited by floating vegetation or by icebergs. The occurrence of boulders in a similar stratigraphical position in the Woolaga Creek and Irwin River sections suggests that they have been dumped from icebergs during a brief recurrence of glacial conditions in early Caryngina time.

The Caryngina Formation contains interbedded sandstones, which are unknown in the Holmwood Shale. The sandstones are cross-bedded, ripple-marked, generally well-sorted, often feldspathic, and locally contain worm tracks. Collectively, these factors suggest the activity of waves and currents in a shallow-water sea, into which both fine and subordinate coarse sediment were being deposited.

It would seem that the "bar" responsible for the euxinic conditions within the basin was not as effective as in Holmwood times.

Wagina Sandstone

(i) *Stratigraphy.*—The name Wagina Sandstone was proposed by Clarke *et al.* (1951) for the sequence of white and red sandstones overlying the Caryngina Formation. These authors measured a maximum thickness of 300 feet in the type section, which is located on the south branch of the Irwin River, near Wagina Well.

The Wagina Sandstone is much thicker in the Woolaga Creek area than in the type area. The upper limit of the formation is unknown as it is everywhere truncated by the Darling Fault, or by the Victoria Plateau surface.

Plant fossils are found profusely in the Wagina Sandstone, at a single locality in the Woolaga Creek area (Plate 1, 4). Apart from this occurrence, which is described below in the reference section, the formation appears to be unfossiliferous. Farther north, in the Irwin River area, exceptionally well preserved plant fossils are recorded from another isolated horizon in the otherwise unfossiliferous Wagina Sandstone (Clarke *et al.* 1951, p. 67).

The reference section in the Woolaga Creek area commences at Red Hill (647838) and extends eastward to the axis of the drag syncline (654845) adjacent to the Darling Fault. The following is a description of this section.

Wagina Sandstone (796 feet +):

Unit	Thickness Feet
5. No outcrop. White sandy soil.	202
4. Sandstone, mottled purple and white, ferruginous, very fine-grained, non-friable, massively bedded (basal 9 inches); succeeded by sandstone, red with minor white banding, ferruginous, quartzose, medium-to coarse-grained, non-friable, moderately well sorted, sub-rounded grains, massively bedded.	12
3. Rapidly alternating sequence. Sandstone, white with minor yellow banding, argillaceous, quartzose, coarse-grained, sometimes conglomeratic, poorly sorted, sub-angular grains, massively bedded; occurs in bands and lenses ranging from ½-inch to 2 feet, but averaging 6 inches in thickness. Siltstone and shale, mainly chocolate, also grey and black, carbonaceous,	

jarositic, micaceous, thin- to thick-bedded, plant fossils abundant; occurs in bands ranging from ½-inch to 6 feet in thickness, commonly 1½ feet thick. Minor thin intercalations of shale, yellow-brown, ferruginous, jarositic, thin-bedded, resistant, rich in plant fossils. Twelve feet above base of unit is 1½-foot band of conglomerate, white, sandy, ill-sorted, containing pebbles of gneiss and quartzite; a similar conglomeratic band, 2 feet thick, occurs 33 feet above base of unit. 56

2. Sandstone, white, with occasional minor red mottling, quartzose, clayey, dominantly fine-grained, also medium-grained, non-friable, generally well-sorted, sub-rounded to rounded grains, massively bedded, occasionally cross-bedded on small scale in restricted bands, sometimes irregularly jointed; minor lenses (up to 9 inches thick) of sandstone, white, silty, coarse-grained, poorly sorted; rare thin bands of siltstone, white, clayey, micaceous, bedded. 522

1. Sandstone, red, ferruginous, silty, fine- to medium-grained, non-friable, moderately sorted, sub-rounded grains, massively bedded. 4

Carynginia Formation (844 feet).

The Wagina Sandstone is a rather monotonous sequence of massively bedded, white and occasionally red sandstone and rare conglomerate, with plant-bearing intercalations of siltstone and shale near the top.

In the north-eastern part of the area, the Wagina Sandstone crops out extensively on the breakaway slopes, which appear conspicuously white even when viewed from some distance. Also, the formation is well-exposed immediately north of the Mingenew-Morawa road for some distance along Ebano Creek, to the east of Ebano Spring. The country underlain by the Wagina Sandstone has a characteristic white sandy soil.

The Wagina Sandstone rests conformably upon the Caryngìnia Formation. Although the contact between the Wagina Sandstone and the Archaean rocks is not exposed, it can generally be established with precision from the air photographs (see **General Geology**).

The Wagina Sandstone attains a thickness of 796 feet along the Woolaga Creek reference section, in contrast to the type section in the Irwin River area which is only 300 feet thick.

(ii) *Biostratigraphy*.—The only fossils discovered in the Wagina Sandstone in the area under consideration were plant impressions from unit 3 of the reference section (see Plate 1, 4). These include *Glossopteris, Gangamopteris,* and *Vertebraria,* all of which are characteristic genera of the Gondwana flora, and hence indicate a Permian age for the formation.

McWhae *et al.* (1958) believe that the Wagina Sandstone is of Artinskian age.

(iii) *Environment of Deposition*.—The abrupt change from the jarositic siltstones of the marine Caryngìnia Formation to the argillaceous quartz sandstones of the Wagina Sandstone suggests a radical change in conditions of sedimentation. Furthermore, the relatively uniform lithology of the Wagina Sandstone is evidence that these new conditions persisted practically unchanged throughout the remainder of the documented Permian in the Woolaga Creek area.

The present author is in agreement with P. E. Playford and S. P. Willmott (in McWhae *et al.* 1958) that the environment of deposition was probably continental. However, the evidence for this is by no means conclusive.

The intercalations of plant-bearing siltstone and shale near the top of the exposed Wagina Sandstone point to continental deposition, but the remaining bulk of the formation, consisting of unfossiliferous, massive, white sandstone offers little corroborative evidence for either a marine or a non-marine environment. However, the general lack of fossils in such a sequence does suggest that it is continental rather than marine. Active reworking of the sediment in a stable environment of low relief is indicated by the well-sorted nature of the sandstone and its lack of feldspathic constituents.

Structure

The Permian sediments of the Woolaga Creek area are on the down-thrown, western side of the meridional Darling Fault, which is the major controlling structural feature of the area. The strata have a gentle easterly tilt and are deformed against the Archaean rocks along the Darling Fault. Proceeding eastwards, then, we encounter rocks progressively higher in the Permian succession, from the Nangetty Formation in the extreme south-western part of the area to, ultimately, the Wagina Sandstone adjacent to the fault line in the north-eastern portion.

The dip of the sediments increases eastward toward the Darling Fault, where the down-throw movement has been greatest. Thus, the dip in the Holmwood Shale, in the western part of the area, is generally about 4° to the east, whereas farther east an easterly dip of 10° is usual in the Irwin River Coal Measures. At Red Hill, the contact between the Caryngìnia Formation and the Wagina Sandstone dips east at 12°. The easterly dip in the Wagina Sandstone one quarter of a mile west of the Darling Fault is 18° (see Plate 1, 4.)

Synclinal drag effects cause westerly dips in strata close to the Darling Fault. At (649857), the westerly dip of the Wagina Sandstone decreases (from east to west) from 60° to 17° in a distance of 20 yards. This outcrop is on the south bank of Ebano Creek, 300 yards west of the Darling Fault line.

In the eastern part of the area, the formations are bent against the Darling Fault, so that, to the south, they effectively enclose the marginal syncline. Hence the syncline is plunging north, and at a fairly low angle. Thus, the Wagina Sandstone (in the north), the Caryngìnia Formation and, finally, the Irwin River Coal Measures (in the south) are found successively along the Darling Fault line in abutment with the Archaean rocks. Field mapping shows that the prominent boundary between the Caryngìnia Formation and the

Wagina Sandstone is deflected through 145° within a distance of one half a mile marginal to the Darling Fault.

An excellent exposure of the marginal drag effect is seen in breakaways in the general vicinity of (652844), south of the Mingenew-Morawa road. Here, the elongate, curving shapes of the hills reproduce faithfully the western limb of the syncline and its southerly closure, and the trends are illustrated strikingly by the air photographs.

A small isolated basin, truncated abruptly on its eastern margin by the Darling Fault, is developed in lateritized strata of the Irwin River Coal Measures. This structure, which is also very well delineated on the air photographs, has a meridional extent of three-eighths of a mile and is one-eighth of a mile wide. It is more precisely described as a doubly plunging syncline (Billings 1954, p. 49), and its restricted form has evidently resulted from a local change in the general northerly plunge of the synclinal axis adjacent to the Darling Fault.

From Plate IV in Johnson *et al.* (1954) it appears that the synclinal axis undergoes repeated and somewhat irregular reversals of plunge to the north of the Woolaga Creek area, with the Wagina Sandstone or immediately underlying formations thrown against the Archaean rocks.

Away from the Darling Fault, the strike of the sediments throughout most of the area averages 145°, although in the general vicinity of Mt. Budd, the prevailing strike is about 110°.

The Darling Fault has a uniform trend of 155° in the Woolaga Creek area. The factors responsible for the clarity with which this major structure is visible on the air photographs, have been discussed previously under **General Geology.** The almost perfectly linear trace of the fault, virtually independent of topography, indicates a vertical or near-vertical dip. As viewed from the air photographs, the Darling Fault appears to have a very steep westerly dip at two localities (666827) and (676806). However, at (673813), the dip appears to be steeply to the east.

The throw of the Darling Fault can be estimated only within very broad limits. It must be not less than the total thickness of the Permian strata, and would seem to be very much greater when the immense thickness of the Yandanooka Group is taken into consideration.

The last movement on the Darling Fault in the Woolaga Creek area was post-Permian, pre-lateritization, and probably pre-Jurassic. Other active phases of the Darling Fault, however, are believed to date back to Precambrian times (Clarke *et al.* 1951, p. 69).

The Permian strata have been disturbed by relatively minor gravity faulting. The faults have small lateral extent, are usually parallel to the strike of the sediments, and generally appear to cause only minor displacements. In most instances, the down-thrown block is to the east. That is, the faults are generally antithetic with respect to the Darling Fault, and consequently result in loss of stratigraphic section. They are recognizable in the field commonly as narrow, often ferruginized or silicified zones of relatively steeply dipping strata.

A good example, previously described, occurs in unit 3 of the High Cliff Sandstone.

At (646873) in the north-eastern part of the area, the Wagina Sandstone is fractured by a fault adjacent and parallel to the Darling Fault. It is an antithetic, normal fault dipping very steeply to the east and is well-displayed by the air photographs.

As noted previously, the contact between the High Cliff Sandstone and the Irwin River Coal Measures is a fault plane in three separate localities.

A small strike fault of westerly throw is exposed at (634836) in siltstones and sandstones of the Irwin River Coal Measures. The fault plane stands out as a resistant ferruginized zone dipping to the west at 57°.

There is no evidence of compressive folding in the Permian strata of the Woolaga Creek area.

Geological History

Previous palaeogeographic interpretations, including those given by Woolnough and Somerville (1924), Woolnough (1937), Clarke *et al.* (1951) and Johnson *et al.* (1954), have been based mainly on the geological record preserved in the Irwin River area. It will be seen from the following paragraphs that the geological histories of the Woolaga Creek and Irwin River areas are essentially similar, which is logical in view of the stratigraphic parallelism in the two areas.

The first recorded event in the geological history of the Woolaga Creek area was the deposition of glacial and fluvio-glacial sediments in a frigid climate characteristic of the earliest Permian throughout Gondwanaland. The glacial Nangetty Formation has only minor representation in the Woolaga Creek area.

The succeeding Holmwood Shale was deposited in a marine environment of restricted circulation, probably in an extensive landlocked bight separated from the open ocean by a bar zone. The location of this "bar" is uncertain, but it may have been to the west or south. The climate was apparently cold, though not as extreme as in the earlier Nangetty times, and occasional erratic boulders in the formation suggest "dumping" from contemporary icebergs. The fossiliferous Woolaga Limestone Member is evidence of an interlude of normal marine conditions in the basin, and suggests a period of ineffectiveness of the barrier. Other limestone beds containing rare fossils represent scattered localities over the basin floor of lime-mud deposition associated with somewhat restricted animal communities.

Thus the Sakmarian Stage in the area was characterized by conditions generally unfavourable for animal life, due initially to a frigid climate and later to a euxinic depositional environment.

In early Artinskian time, the Woolaga Creek area possibly underwent some emergence, and the High Cliff Sandstone accumulated under shallow-water marine conditions of normal circulation. A prolific fauna of marine invertebrates thrived in early High Cliff time. The boulders in the middle of the formation may have been deposited from floating ice.

A recession of the sea from the area concluded this shallow-marine interlude, and the Irwin River Coal Measures were next laid down under fluvial and swampy conditions, perhaps as the topset beds of an extensive delta. The land was vegetated by typical representatives of the *Glossopteris* flora. The erratic boulders, which are also present in this formation, may have been rafted in by either floating vegetation or icebergs.

The transitional boundary between the Irwin River Coal Measures and the overlying Carynginia Formation records a gradual deepening of the depositional basin and the re-establishment of marine conditions throughout the area. The Carynginia Formation, with its predominant jarositic siltstones, represents an interesting recurrence of the stagnant barred basin environment of Holmwood time. However, the presence of abundant sandy intercalations with ripple-marking, cross-bedding and worm tracks attests to somewhat shallower conditions, with greater influence of waves and currents than in Holmwood time. A cold prevailing climate with contemporary floating ice is again suggested by the "dumped" erratics in the basal part of the Carynginia Formation.

The abrupt change from the Carynginia Formation to the succeeding non-marine Wagina Sandstone points to a sudden disappearance of the sea from the area and a return to continental conditions. Plant-bearing siltstones and shales near the top of the Wagina Sandstone indicate the existence of the *Glossopteris* flora. The Wagina Sandstone may be Artinskian in age, and represents the final fragment of palaeogeographic evidence of the Permian Period in the Woolaga Creek area.

Large-scale, west-block-down movement occurred along the Darling Fault at some stage following Wagina times, and certainly prior to lateritization. This resulted in the easterly tilt of the Permian strata and their marginal deformation against the Archaean complex. Gravity faulting within the Permian rocks may have preceded the Darling Fault activity, but it seems more likely to have occurred during this important tectonism as relatively minor adjustments of the sediments.

The area was subsequently eroded and reduced to a peneplain, probably by early Tertiary times. Arenaceous continental rocks were deposited sporadically over this surface of low relief. The area was then elevated and the resultant plateau subjected to intensive dissection. The cuirass of duricrust with its associated sand-plain developed during a climate having the requisite seasonal distribution of rainfall. This lateritization resulted in superficial alteration of both the Permian and Archaean rocks.

Erosion by the existing river system has continued through the Quaternary to the present day with the removal of much of the Victoria Plateau surface and the consequent widespread exposure of the underlying Permian strata.

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References

Billings, M. P. (1954).—"Structural Geology." 2nd Ed. (Prentice-Hall: New York.)

Campbell, W. D. (1910).—The Irwin River coalfield and the adjacent districts from Arrino to Northampton. *Bull. Geol. Surv. W. Aust.* 38: 1-108.

Clarke, E. de C., Prendergast, K. L., Teichert, C., and Fairbridge, R. W. (1951).—Permian succession and structure in the northern part of the Irwin Basin, Western Australia. *J. Roy. Soc. W. Aust.* 35: 31-84.

Cotton, C A. (1945).—"Geomorphology." 4th Ed. (Whitcombe and Tombs: Christchurch.)

Dickins, J. M. (1957).—Permian fossils from Woolaga Creek, Irwin Valley, Western Australia. Rec. Bur. Miner. Resour. Aust. 1957/110.

Dickins, J. M., and Thomas, G. A. (1957).—Permian fossils from Carynginia Gully, Irwin River area, Western Australia. Rec. Bur. Miner. Resour. Aust. 1957/69.

Fairbridge, R. W. (1952).—The Permian of South Western Australia. 19th Int. Geol. Congr., Symp. Series Gondwana: 136-146.

Johnson, W., de la Hunty, L. E., and Gleeson, J. S. (1954).—The geology of the Irwin River and Eradu Districts and surrounding country. *Bull. Geol. Surv. W. Aust.* 108: 1-131.

McWhae, J. R. H., Playford, P. E., Lindner, A. W., Glenister, B. F., and Balme, B. E. (1958).—The Stratigraphy of Western Australia. *J. Geol. Soc. Aust.* 4: 1-161.

Miller, A. K. (1947).—Tertiary nautiloids of the Americas. *Mem. Geol. Soc. Amer.* 23: 1-114.

Playford, P. E. (1954).—Observations on laterite in Western Australia. *Aust. J. Sci.* 17: 11-14.

Prider, R. T. (1952).—South-west Yilgarnia. Sir D. Mawson Anniv. Vol., Univ. Adelaide: 143-151.

Ruzhencev, V. E. (1952).—Biostratigraphy of the Sakmarian Stage in the Aktyubinsk region of Kazakhstan, U.S.S.R. *Acad. Sci. U.S.S.R. Proc. Paleont. Inst.* 42: 1-87.

Stetson, H. C., and Upson, J. E. (1937).—Bottom deposits of the Ross Sea. *J. Sediment. Petrol.* 7: 55-66.

Tasch, P. (1953).—Causes and paleoecological significance of dwarfed fossil marine invertebrates. *J. Paleont.* 27: 356-444.

Teichert, C., and Glenister, B. F. (1952).—Lower Permian ammonoids from the Irwin Basin, Western Australia. *J. Paleont.* 26: 12-23.

Thyer, R. F., and Everingham, I. B. (1956).—Gravity survey of the Perth Basin, Western Australia. *Bull. Bur. Miner. Resour. Aust.* 33: 1-11.

Twenhofel, W. H. (1950).—"Principles of Sedimentation." (McGraw-Hill: New York.)

Woolnough, W. G. (1937).—Sedimentation in barred basins and source rocks of oil. *Bull. Amer. Ass. Petrol. Geol.* 21: 1101-1157.

Woolnough, W. G. (1938).—Fact and theory in geology with special reference to petroleum, salt and coal. *Rep. Aust. Ass. Adv. Sci.* 23: 54-79.

Woolnough, W. G., and Somerville, J. L. (1924).—A contribution to the geology of the Irwin River Valley of Western Australia. *J. Roy. Soc. N.S.W.* 58: 67-112.

1

2

3

4

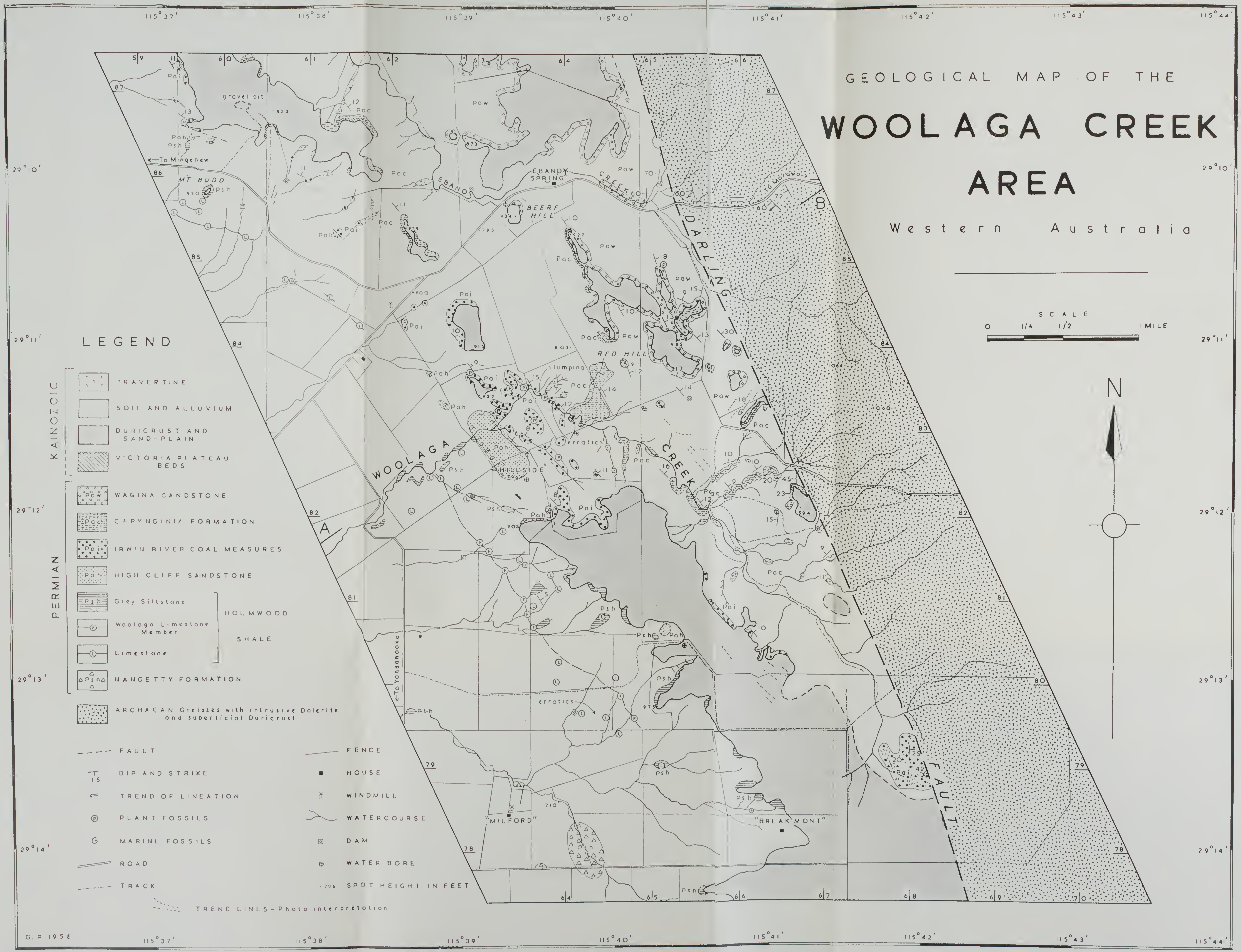
PLATE 1

1.—North-eastern aspect of Mt. Budd, an impressive butte, composed of Holmwood Shale and capped by the resistant lateritic surface of the Victoria Plateau.

2.—Slumping in the Irwin River Coal Measures at (638834), on the west bank of Woolaga Creek.

3.—Northern aspect of Red Hill, a butte, which consists of Carynginia Formation overlain near the top by a thin capping of Wagina Sandstone. The breakaways to the left (east) expose Wagina Sandstone.

4.—Plant fossil locality in the Wagina Sandstone at (651849), on the northern point of a narrow mesa. The strata are dipping comparatively steeply to the east, and are on the western limb of the drag syncline adjacent to the Darling Fault.


GEOLOGICAL MAP OF THE
WOOLAGA CREEK
AREA
Western Australia
SCALE
0 1/4 1/2 1 MILE
N
LEGEND
KAINOZOIC
TRAVERTINE
SOIL AND ALLUVIUM
DURICRUST AND SAND-PLAIN
VICTORIA PLATEAU BEDS
PERMIAN
WAGINA SANDSTONE
CAPYNGINIA FORMATION
IRWIN RIVER COAL MEASURES
HIGH CLIFF SANDSTONE
Grey Siltstone
Woolaga Limestone Member
Limestone
HOLMWOOD SHALE
NANGETTY FORMATION
ARCHAEAN Gneisses with intrusive Dolerite and superficial Duricrust
FAULT
DIP AND STRIKE
TREND OF LINEATION
PLANT FOSSILS
MARINE FOSSILS
ROAD
TRACK
FENCE
HOUSE
WINDMILL
WATERCOURSE
DAM
WATER BORE
SPOT HEIGHT IN FEET
TREND LINES - Photo interpretation
DARLING FAULT
WOOLAGA CREEK
EBANO CREEK
EBANO SPRING
BEERE HILL
RED HILL
MT BUDD
HILLSIDE
"MILFORD"
"BREAKMONT"
To Mingenew
To Mordwo
To Yandanooka
gravel pit
slumping
erratics
115°37′
115°38′
115°39′
115°40′
115°41′
115°42′
115°43′
115°44′
29°10′
29°11′
29°12′
29°13′
29°14′
G.P. 1958

MAP I.

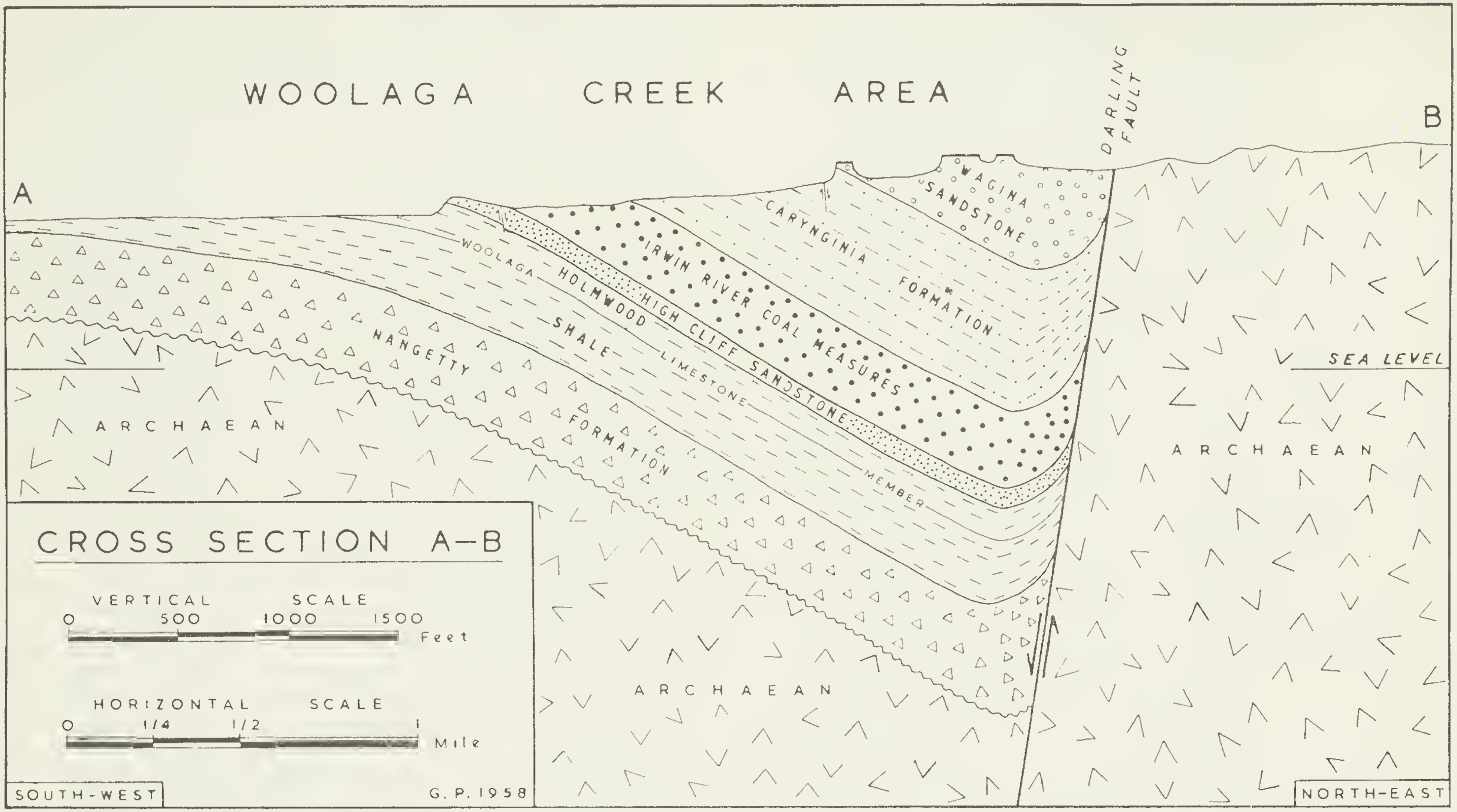
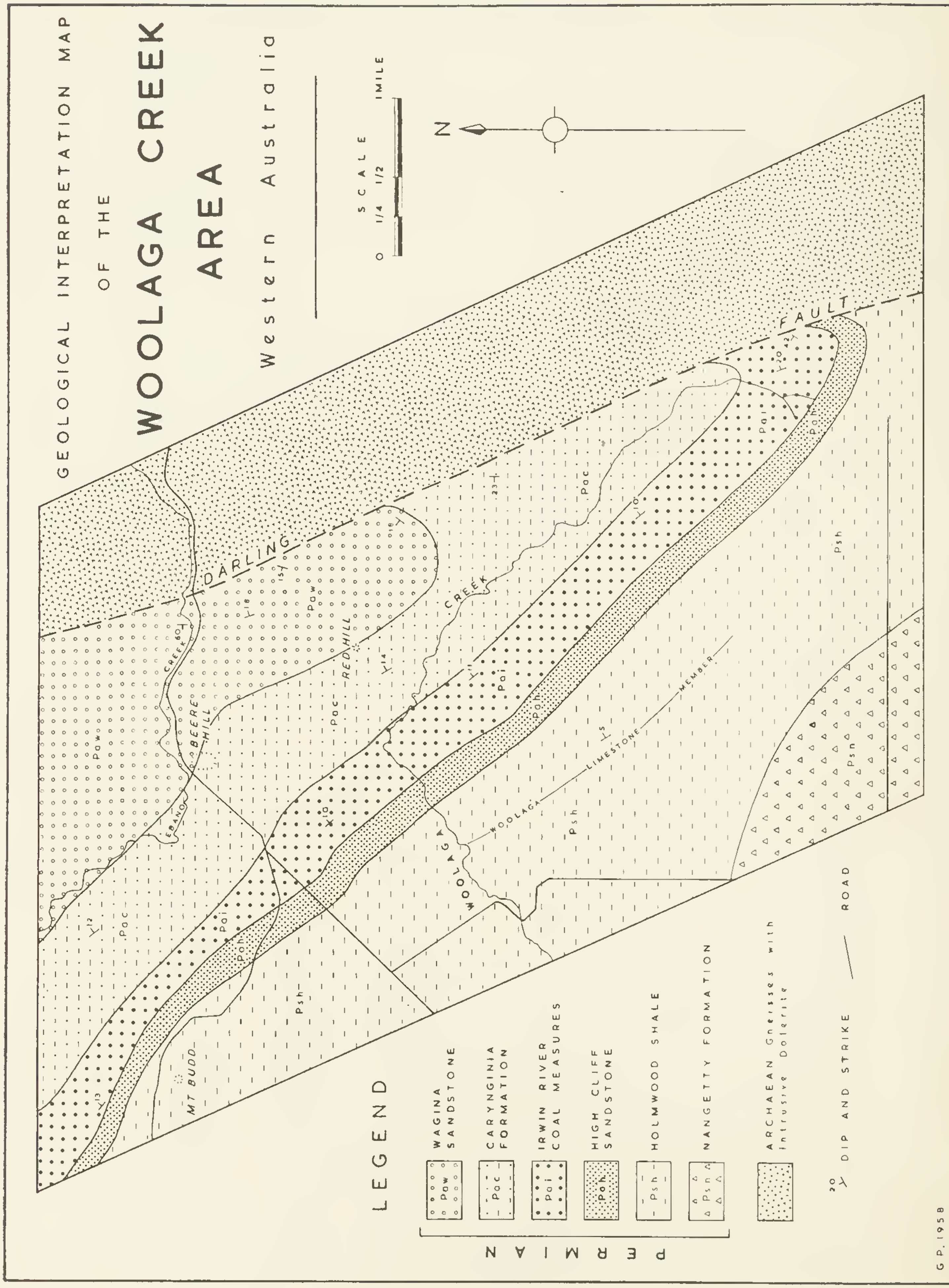


Fig. 3.—Geological cross section from A-B (Map 1).


GEOLOGICAL INTERPRETATION MAP
OF THE
WOOLAGA CREEK
AREA
Western Australia
SCALE
0 1/4 1/2 1MILE
N
DARLING FAULT
WOOLAGA CREEK
CREEK
RED HILL
BEERE HILL
ERANG
MT BUDD
WOOLAGA LIMESTONE MEMBER
LEGEND
PERMIAN
WAGINA SANDSTONE
CARYNGINIA FORMATION
IRWIN RIVER COAL MEASURES
HIGH CLIFF SANDSTONE
HOLMWOOD SHALE
NANGETTY FORMATION
ARCHAEAN Gneisses with intrusive Dolerite
DIP AND STRIKE
ROAD
G.P. 1958

MAP 2.

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